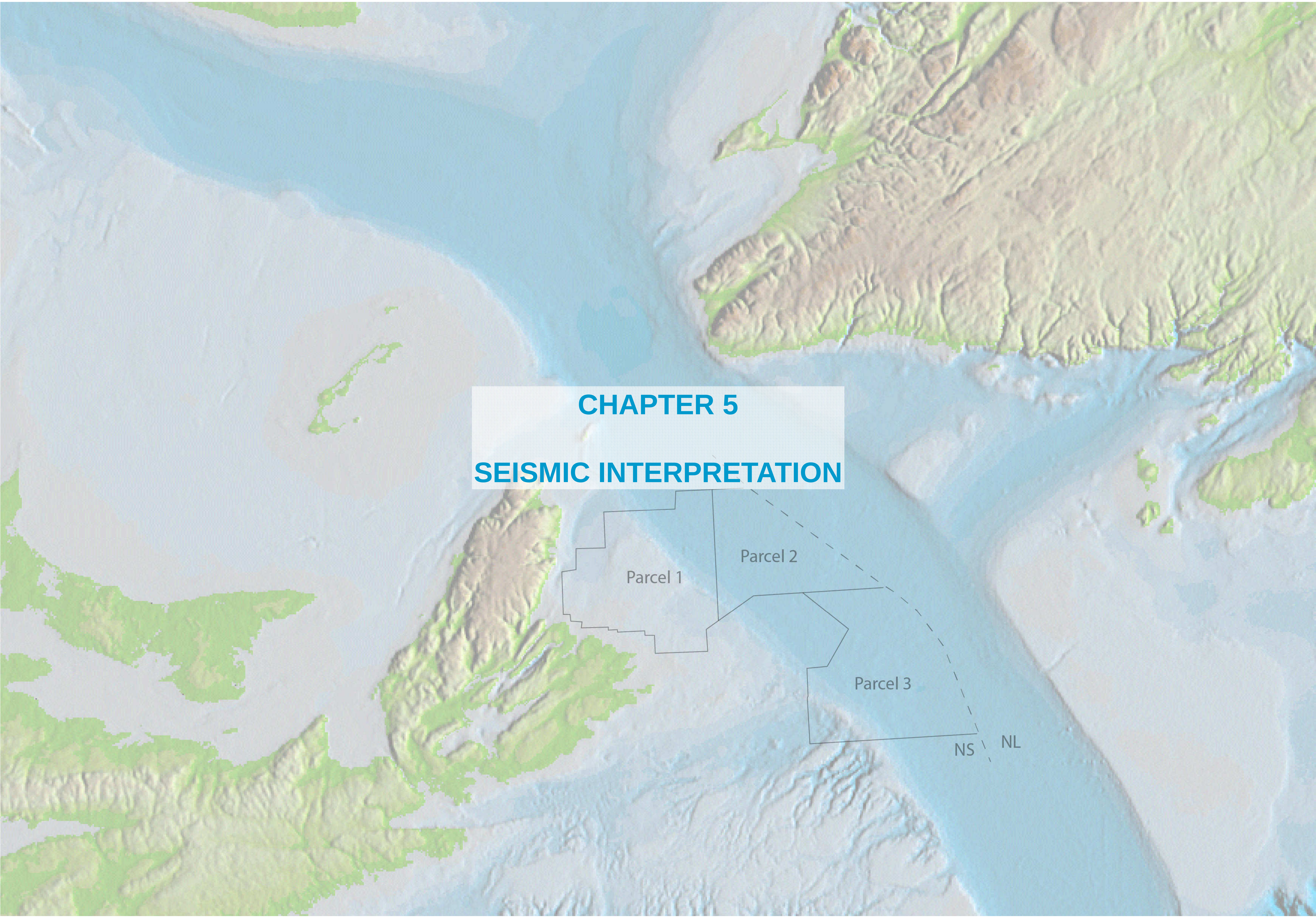
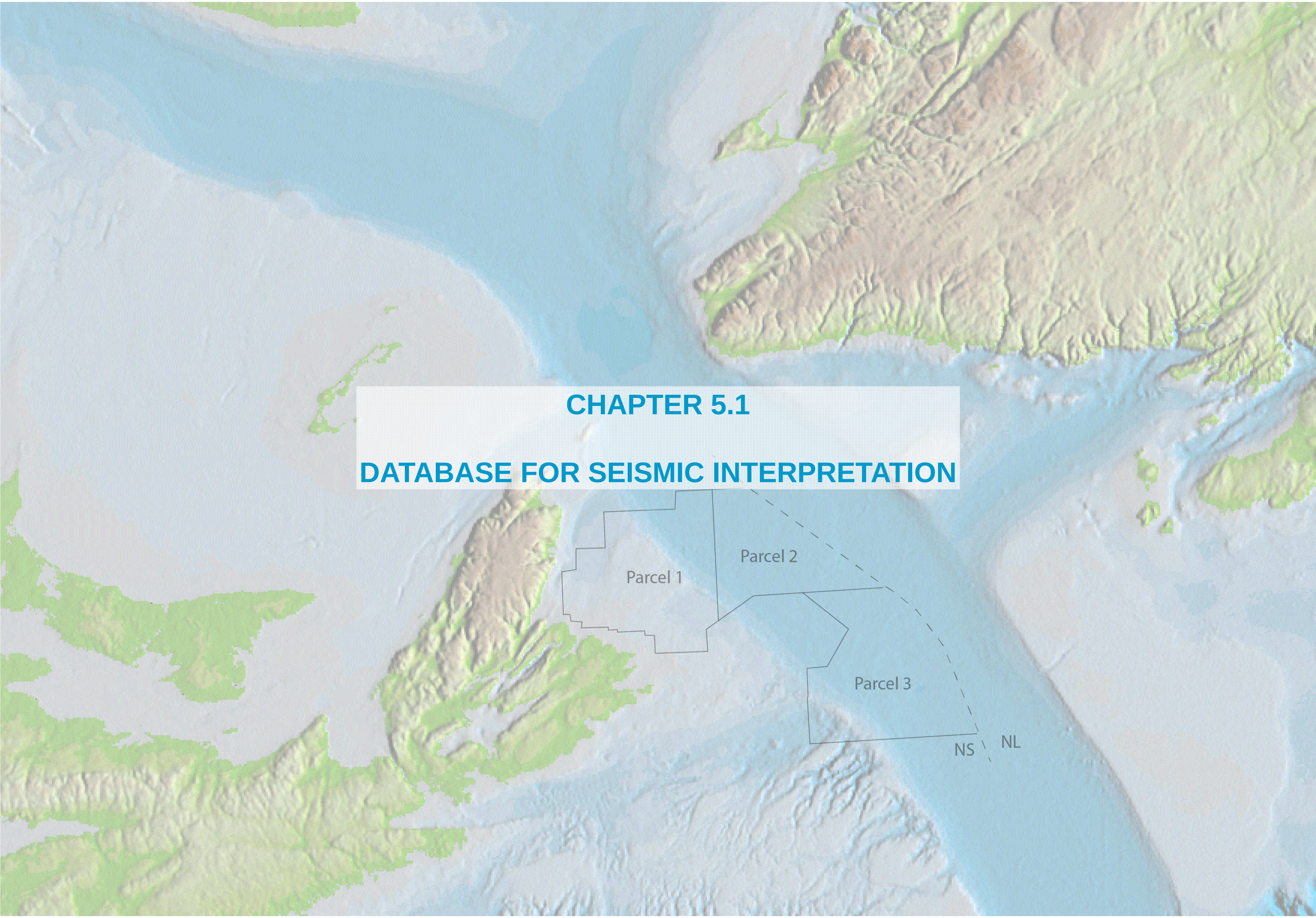
CHAPTER 5

SEISMIC INTERPRETATION



CHAPTER 5.1

DATABASE FOR SEISMIC INTERPRETATION



SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

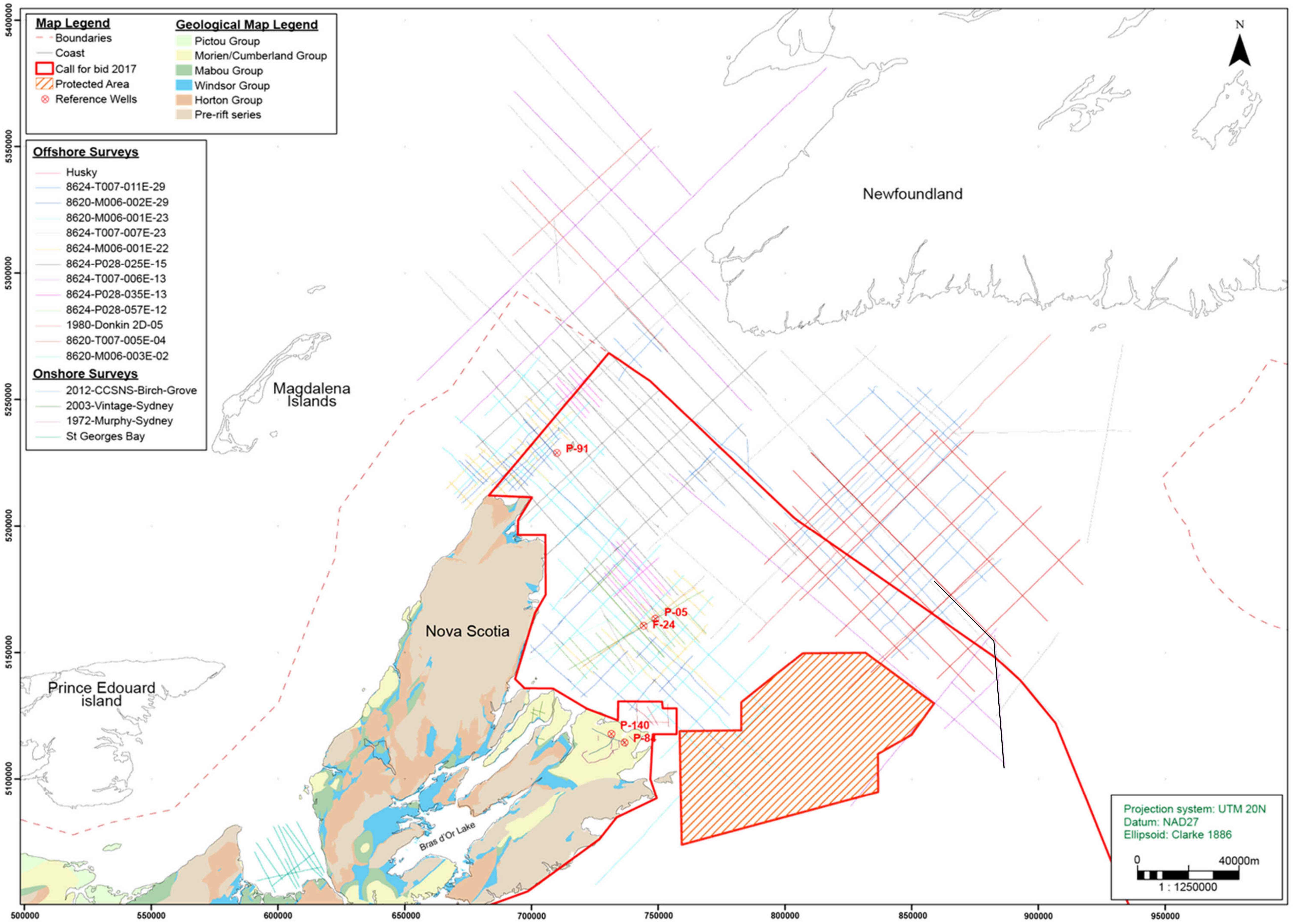


Figure 1: Location map of the seismic surveys

2D surveys

(a)	1981-PetroCanada	15 lines – 1367 km	PreSTM – Reprocessed in 2003 – Multiples present
(b)	1982-PetroCanada	13 lines – 283 km	Stack – Reprocessed in 2003 – Very bad quality lateral reverberation
(c)	1983-PetroCanada	11 lines – 260 km	PreSTM – Reprocessed in 2003 – Multiples present
(d)	8620-M006-001E	22 lines – 1095 km	Scanned stack – 1971 – Many multiples
(e)	8620-M006-002E	32 lines – 641 km	Scanned stack – 1972 – Many multiples
(f)	8620-M006-003E	2 lines – 165 km	Scanned stack – 1974 – Many multiples
(g)	8620-T007-005E	4 lines – 341 km	Scanned stack – 1971 – Many multiples
(h)	8624-M006-001E	22 lines – 467 km	Scanned stack – 1972 – Many multiples
(i)	8624-T007-006E	13 lines – 1061 km	Scanned stack – 1970 – Many multiples
(j)	8624-T007-007E	22 lines – 1621 km	Scanned stack – 1974 – Severe multiples
(k)	8624-T007-011E	13 lines – 1114 km	Scanned stack – 1975 – Severe multiples
(l)	CCSNS*	2 lines – 27 km	PreSTM – 2013 – High frequency seismic
(m)	Donkin	5 lines – 48 km	Stack – 1980 – Severe multiples
(n)	2010 Survey	12 lines – 1129 km	PreSTM – 2010 – Best quality in the offshore area
(o)	Lithoprobe	1 line – 173 km	PSTM – 1981 – Many multiples
(p)	Murphy*	10 lines – 42 km	Stack – 1972 – Bad quality
(q)	VIN03-SYD*	5 lines – 25 km	PoSTM – 2003 – Isolated onshore lines

** onshore surveys*

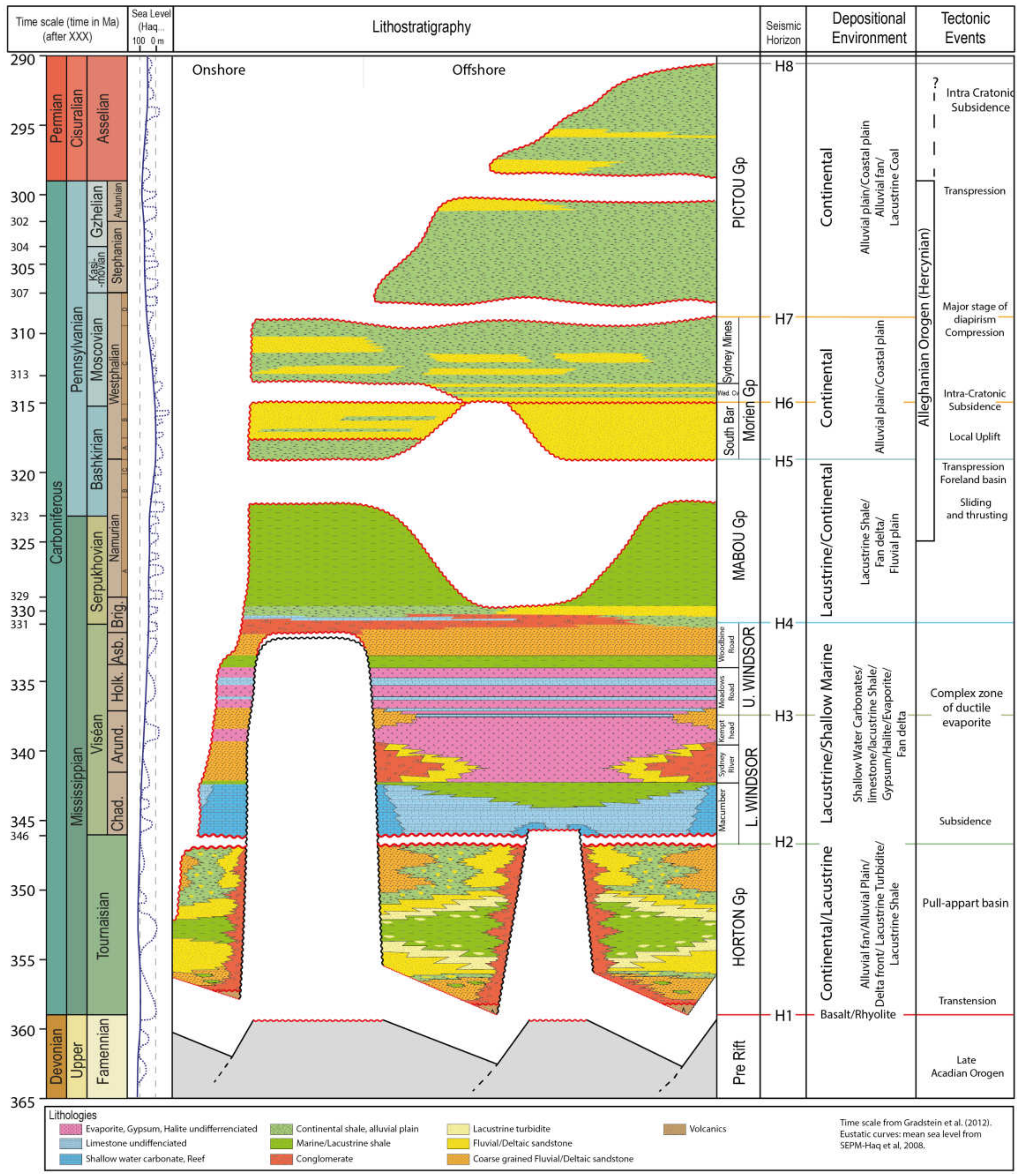


Figure 2: Stratigraphic chart of the Sydney Basin, Nova Scotia

Seismic horizons

All horizons were interpreted from scratch. The seabed was extracted from the public domain (*Atlantic Sea Floor* in m, then converted in TWT with a velocity of 1500 m/s) .

- Top South Bar
- Top Sydney Mines
- Westphalian/Namurian Unconformity
- Top Windsor
- Top Lower Windsor
- Top Horton
- Top Basement

Plate **5.2.1.6** gives the seismic definition in the picking of these horizons.

Seismic database

The seismic interpretation was undertaken on various 2D seismic surveys mainly located **in** Sydney Basin, with some lines also crossing the Cabot Fault complex up to the southeastern part of the Magdalen Basin.
In total, 17 2D seismic surveys were made available for the project as shown in Figure 1, measuring a total length of 9,860 km. They are listed below. Their quality is variable; only the 2010 survey, CCSNS and some PetroCanada reprocessed lines have fair quality.

Example of different survey qualities

The sections below illustrate the great range of seismic quality between the different surveys. They were all taken in the dip direction, perpendicular to the main faulting system, and both lines of each figure are very close to each other (except in Figure 4).

- Figure 1: the best seismic quality is observed in the recent 2010 survey lines (left). These lines are key for interpreting the deepest horizons, i.e. Basement and Horton;
- Figure 2: the 1981- (left) and 1983-PetroCanada reprocessed vintages (not displayed) enable extension of the seismic interpretations in the area between the North Sydney and Saint-Paul wells (PL. 4.1.1 Figure 1);
- Figure 3: the long-range Lithoprobe line (left) gives some details regarding basement structures, but has strong sea bottom peg-legs in the shallow parts which may completely mute the signature of the North Sydney high around both wells;
- Figure 4: example of very low quality surveys: non-migrated 1982-PetroCanada and 8624-T007-011E.

NW **Line 1** (Survey, in red) — **Line K-44** (Survey 8624-T007-007E, in green) SE

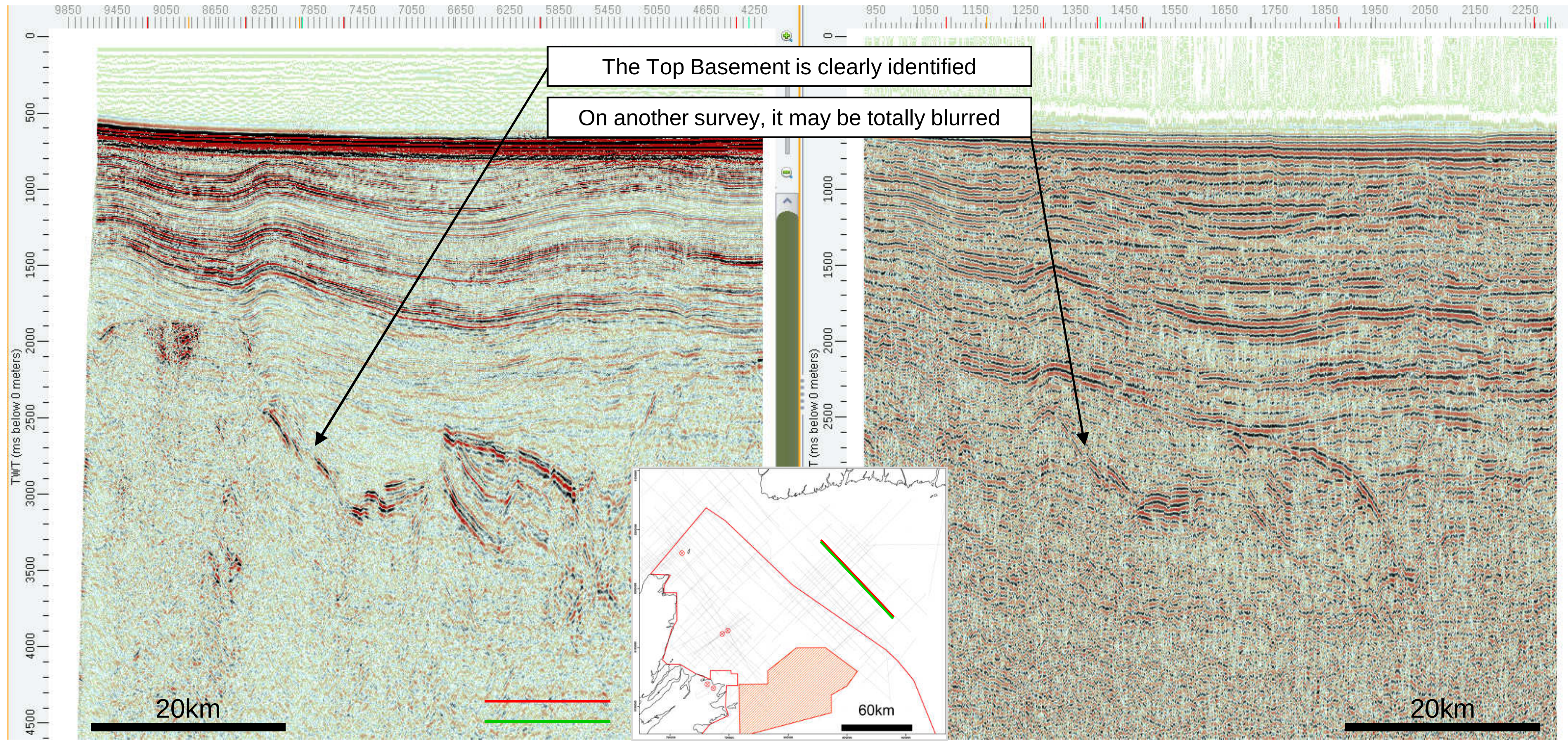


Figure 1: 2010 survey (left/red) vs . 8624-T007-007E (right/green)

NW **Line PCAN81-865a** (Survey Lithoprobe, in red) — **Line Z** (Survey 8620-M006-003E, in green) SE

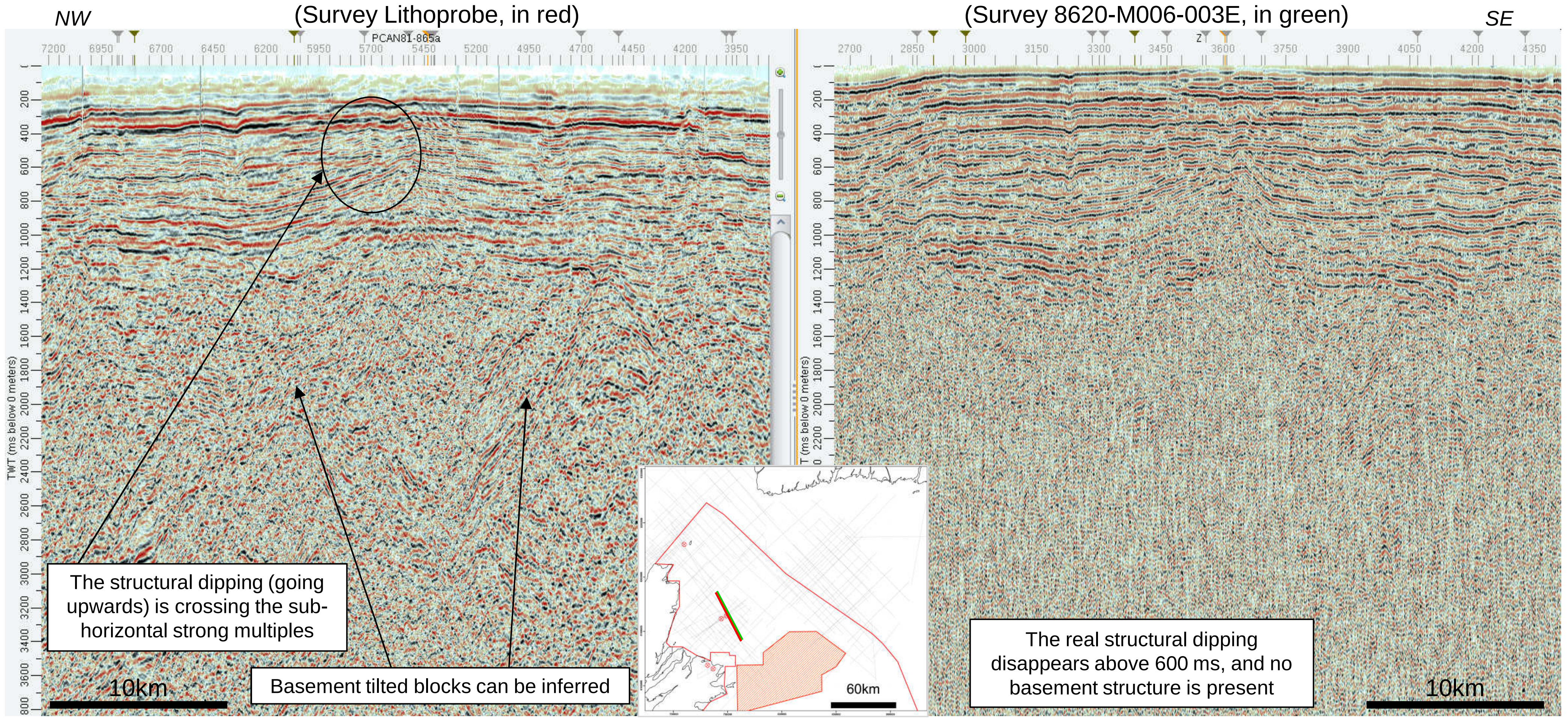


Figure 3: Lithoprobe (left/red) vs . 8620-M006-003E (right/green)

NW **Line 81-1117** (Survey 1984-PetroCanada, in red) — **Line 12** (Survey 8620-M006-001E, in green) SE

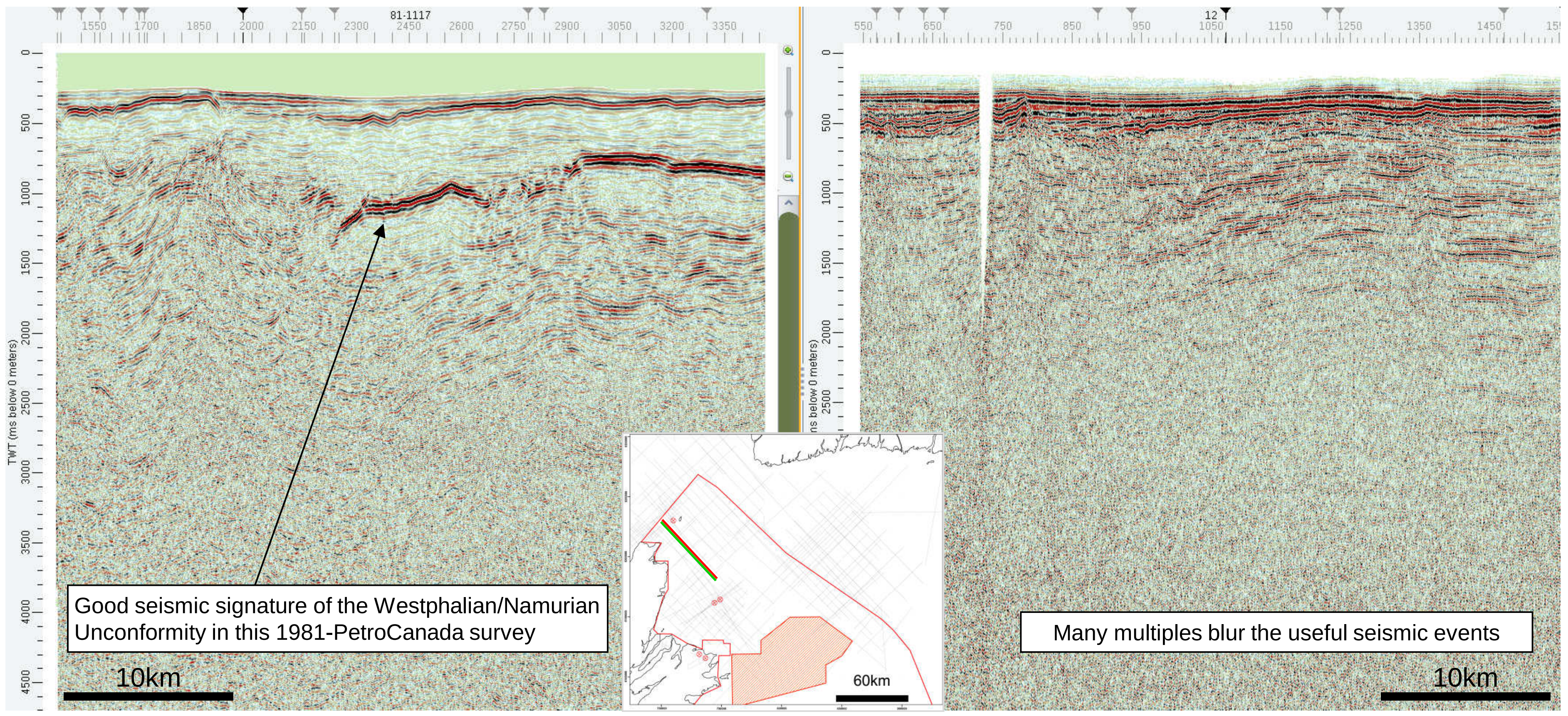


Figure 2: 1981-PetroCanada (left/red) vs . 8620-M006-001E (right/green)

NW **Line 4007** (Survey *1982-PetroCanada*, in red) — **Line D82** (Survey *8624-T007-011E*, in green) SE

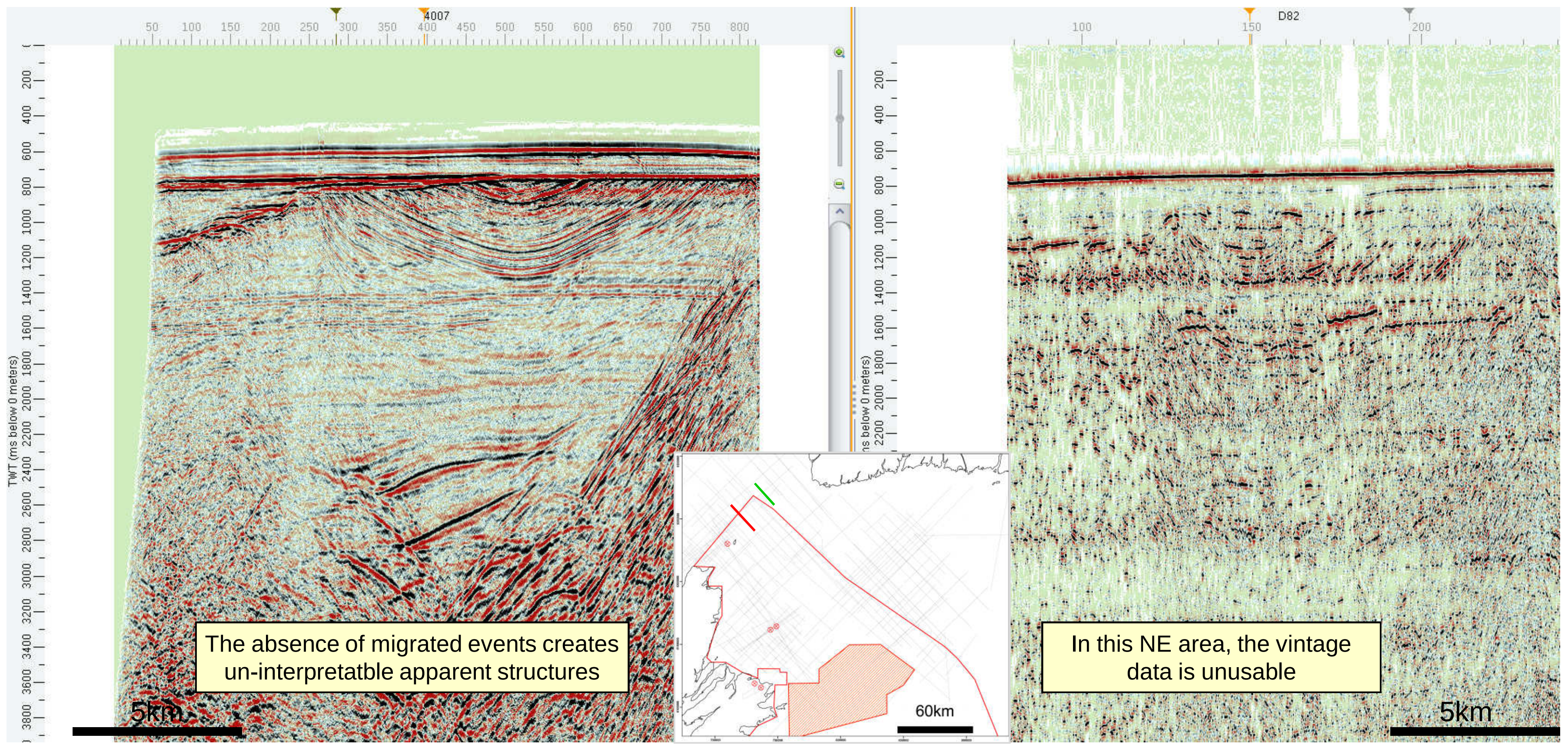
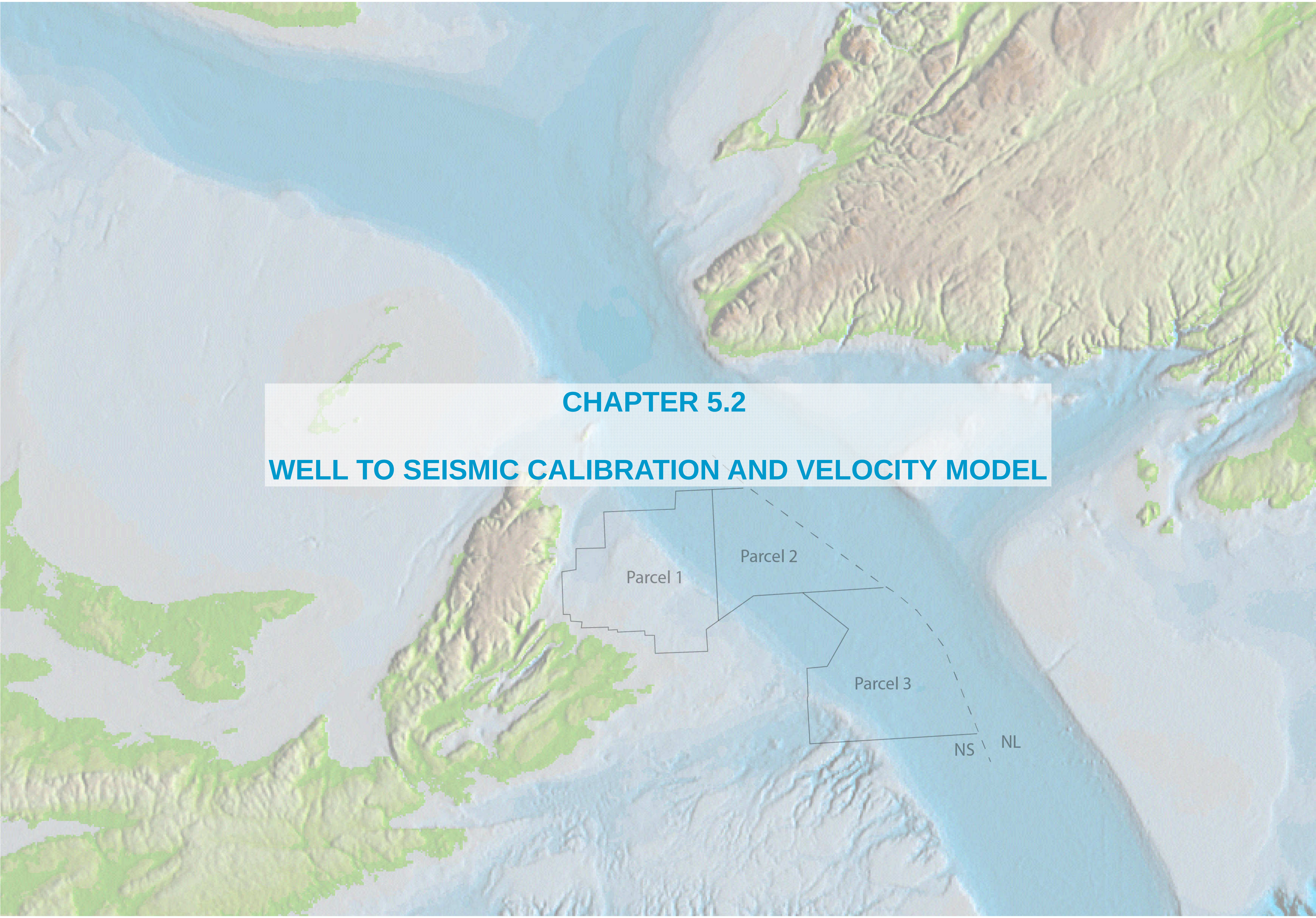


Figure 4: 1982-PetroCanada (left/red) vs . 8624-T007-011E (right/green)

CHAPTER 5.2

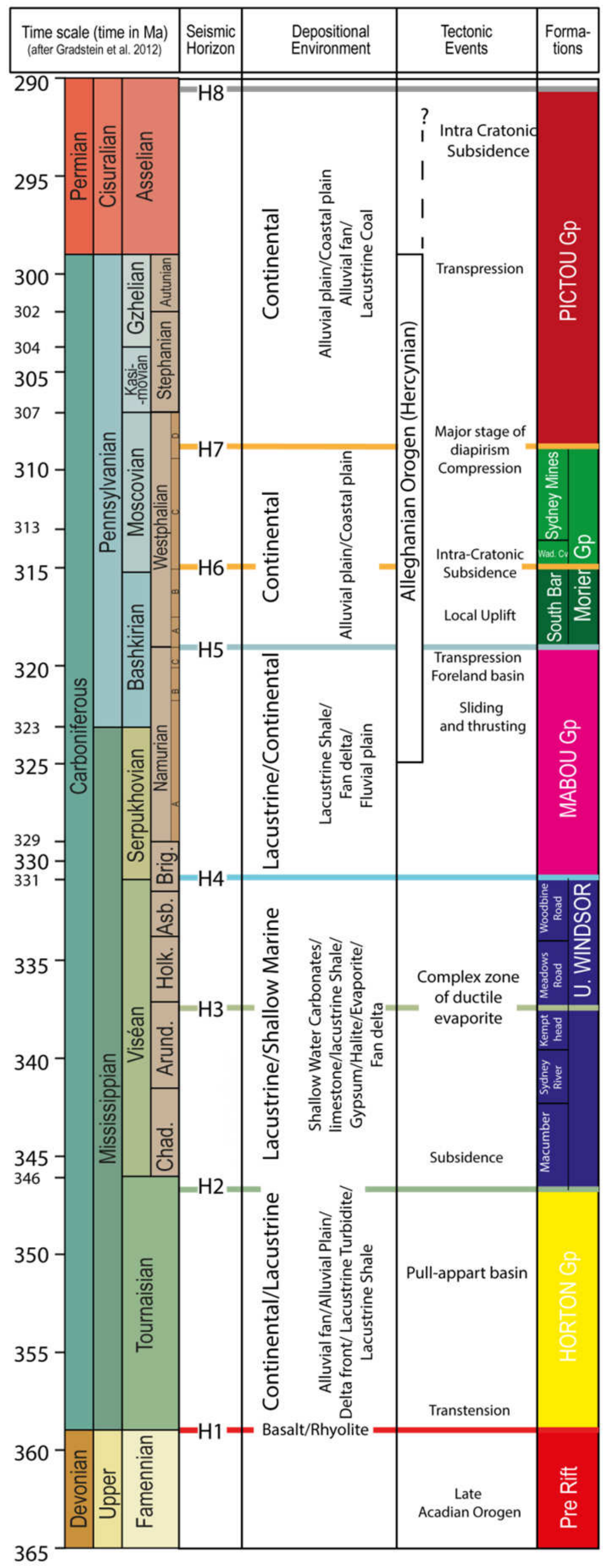
WELL TO SEISMIC CALIBRATION AND VELOCITY MODEL

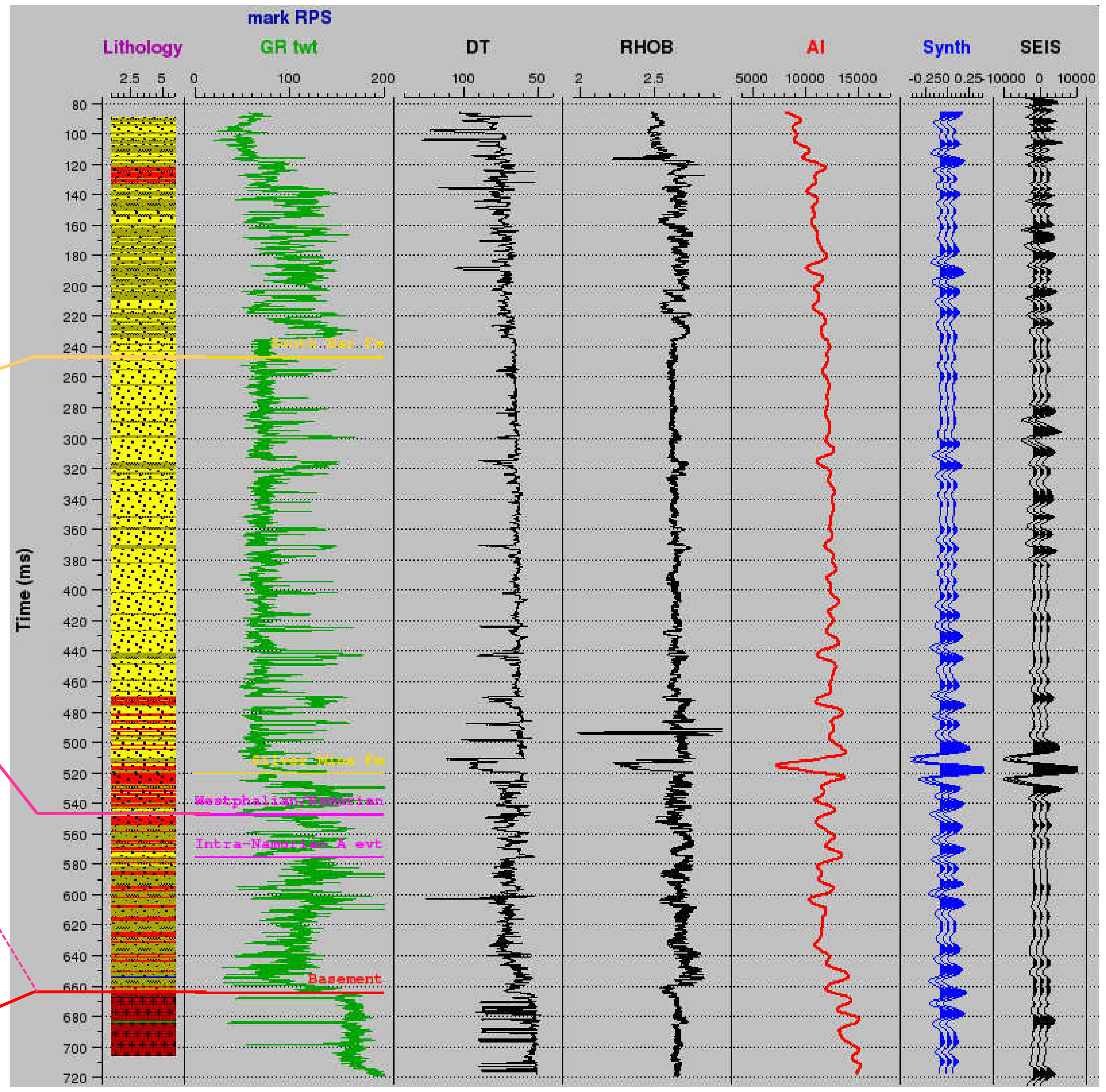


CHAPTER 5.2.1

Section Calibration

SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION





Initial T/D relationship from sonic integration (assessed TWT shift at sonic log origin: 28 ms)
Added TWT shift for synthetic calibration: +58 ms

WELL HEADER		
Well Name	**CCSNS-1 P-140**	
Rotary Table (R.T.)	37.6 m	
Total Depth (T.D.)	1527 m (MD R.T.)	
Geographic coordinates @surface (NAD83)	Lat: 46° 10' 35.62" N	Lon: 59° 59' 55.45" W
UTM coordinates (NAD27, Zone 20N)	X_{UTM} : 731597	Y_{UTM} : 5117822

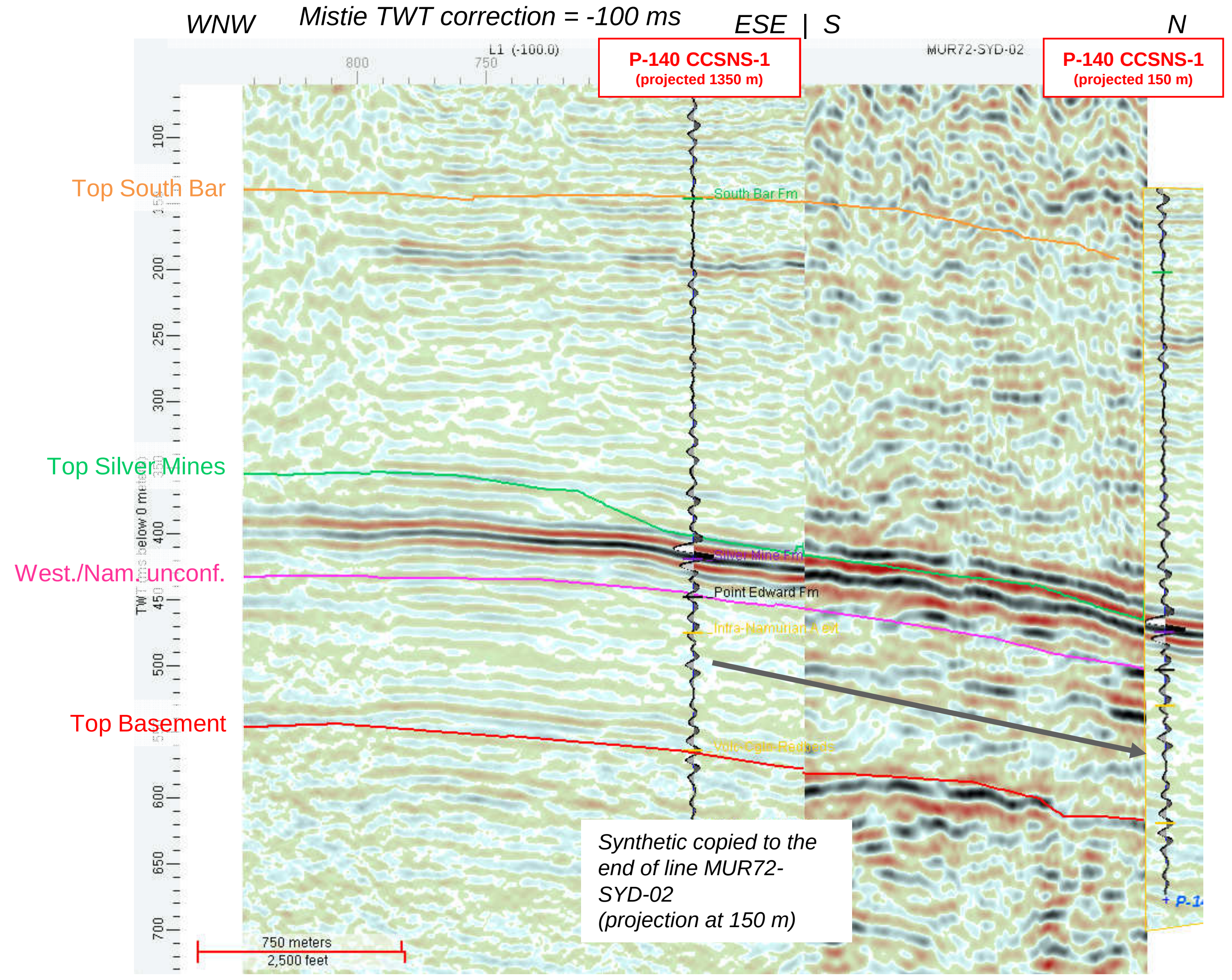
BIOSTRATIGRAPHY	RPS Energy 2017

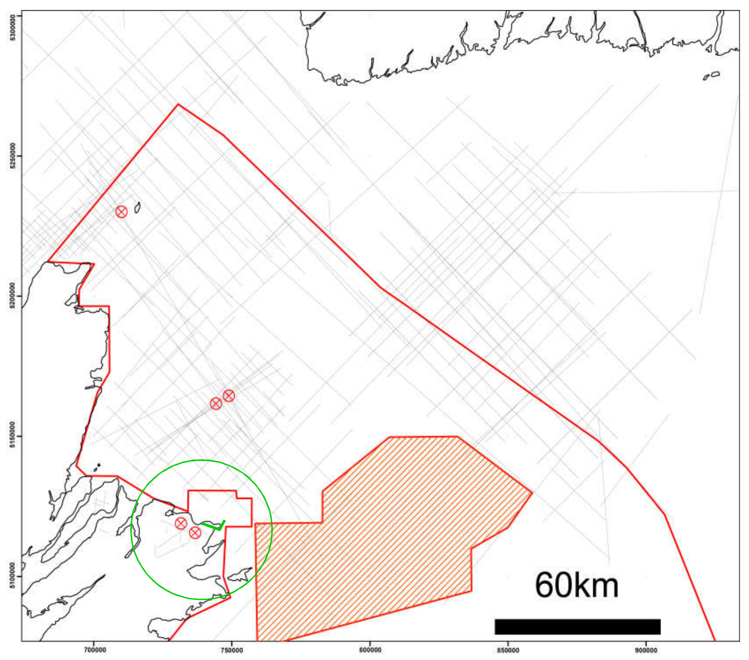
SEISMIC LOCATION	
Survey	CCSNS 2013
Line	L1
CDP / Trace	2748 / 668
Offset (m)	1350

SEISMIC MARKERS

Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	*(onshore)*	*(onshore)*
309	Sydney Mine	*(no data)*	*(no data)*
313	Waddens Cove	*(no data)*	*(no data)*
315	South Bar	247	-380
320	Silver Mine	520	-1012
323	Point Edward – Westphalian/Namurian unc.	548	-1076
329	Cape Dauphin	*(not present)*	*(not present)*
331	Woodbine Road	*(not present)*	*(not present)*
334	Meadows Road	*(not present)*	*(not present)*
339	Sydney River	*(not present)*	*(not present)*
360	Pre-Rift	665	-1335

Survey CCSNS 2013 – line L1
Mistie TWT correction = -100 ms

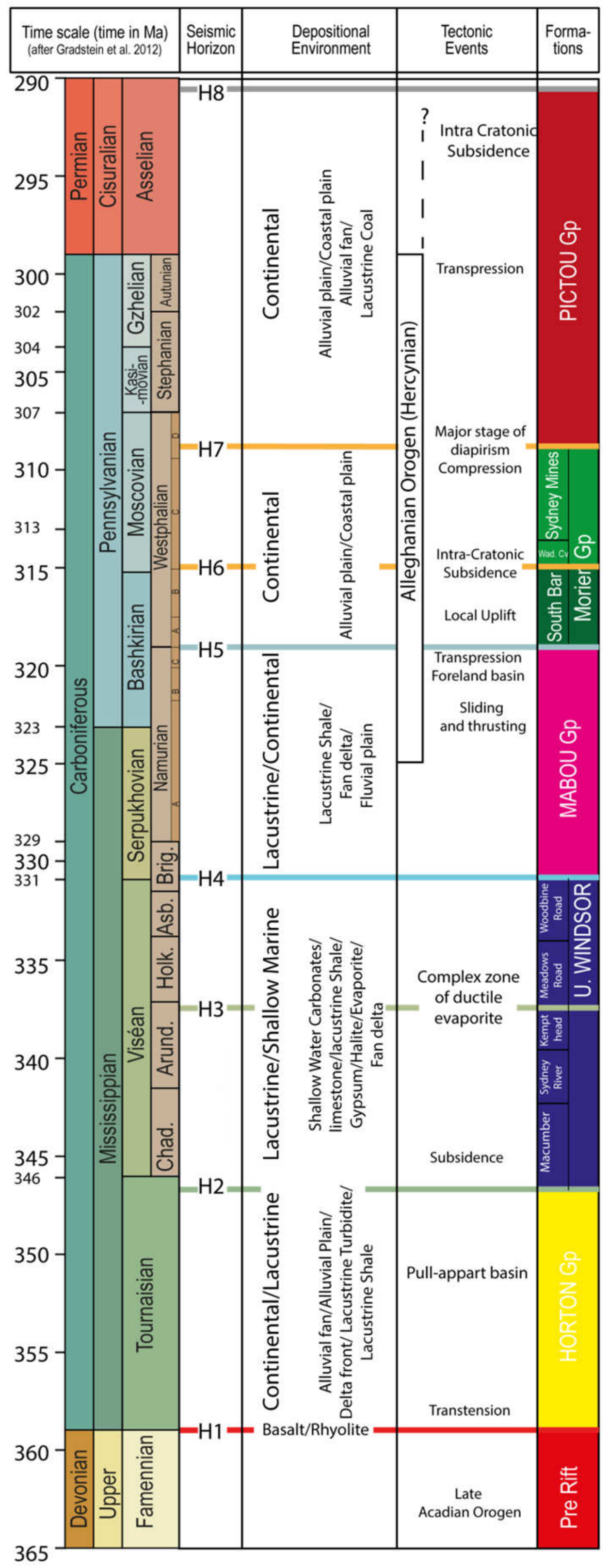


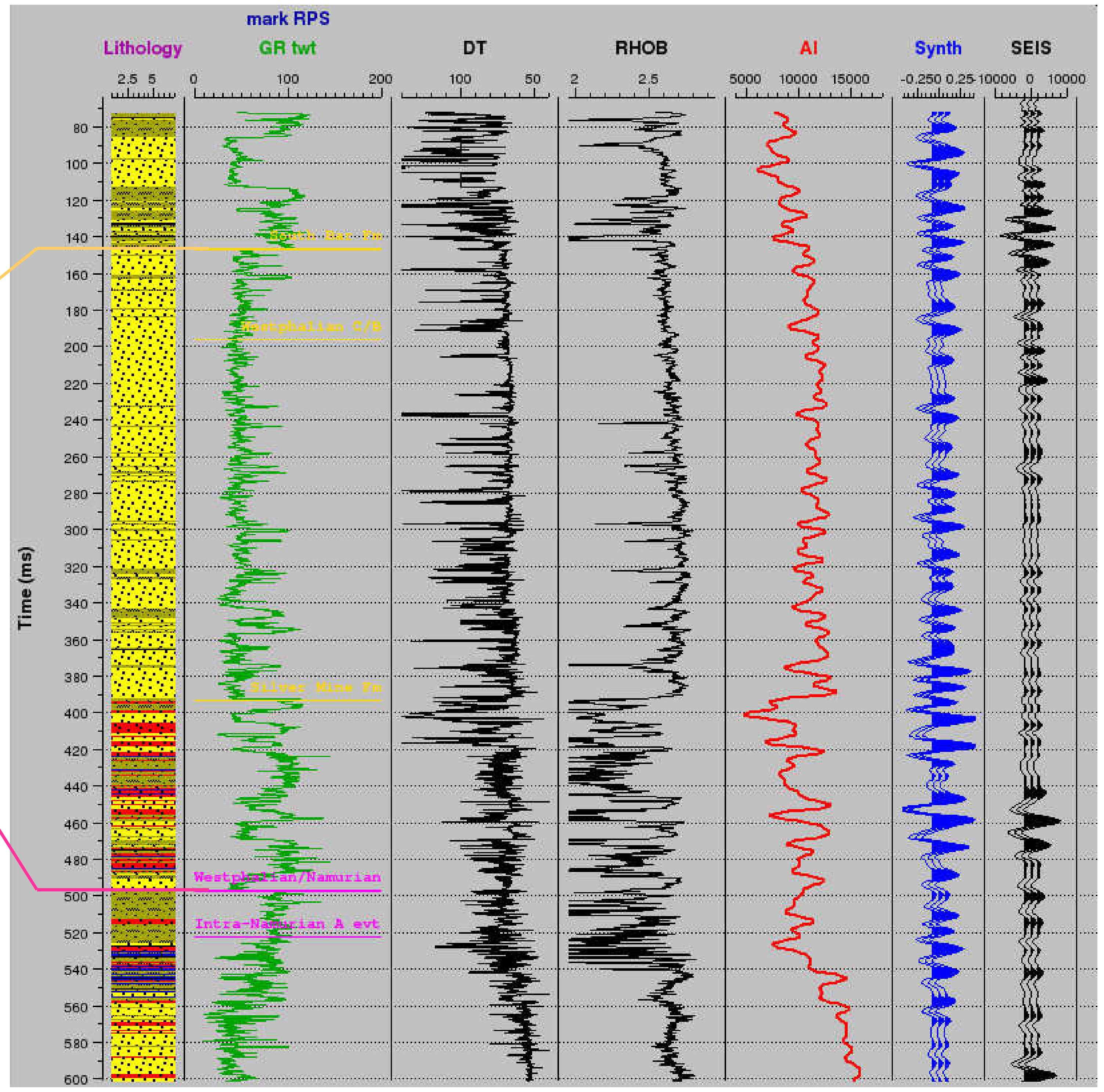


Comments

No checkshot survey was available.
The well was calibrated using the recent CCSNS line (line L1) – 1350 m of offset – that has greater seismic quality rather than the nearest line to the well (MUR72-SYD02 at 150 m from the well). A lateral copy/paste of the synthetic is done at the end of the Murphy line for checking the relevance of this calibration.

SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION





Initial T/D relationship from sonic integration (assessed TWT shift at sonic log origin: 94 ms)
Added TWT shift for synthetic calibration: -22 ms

WELL HEADER		
Well Name	**Birch-Grove-1 P-84**	
Rotary Table (R.T.)	49.7 m	
Total Depth (T.D.)	1344 m (MD R.T.)	
Geographic coordinates @surface (NAD27)	Lat: 46° 08' 42.40" N	Lon: 59° 56' 05.04" W
UTM coordinates (NAD27, Zone 20N)	X_{UTM} : 736732	Y_{UTM} : 5114521

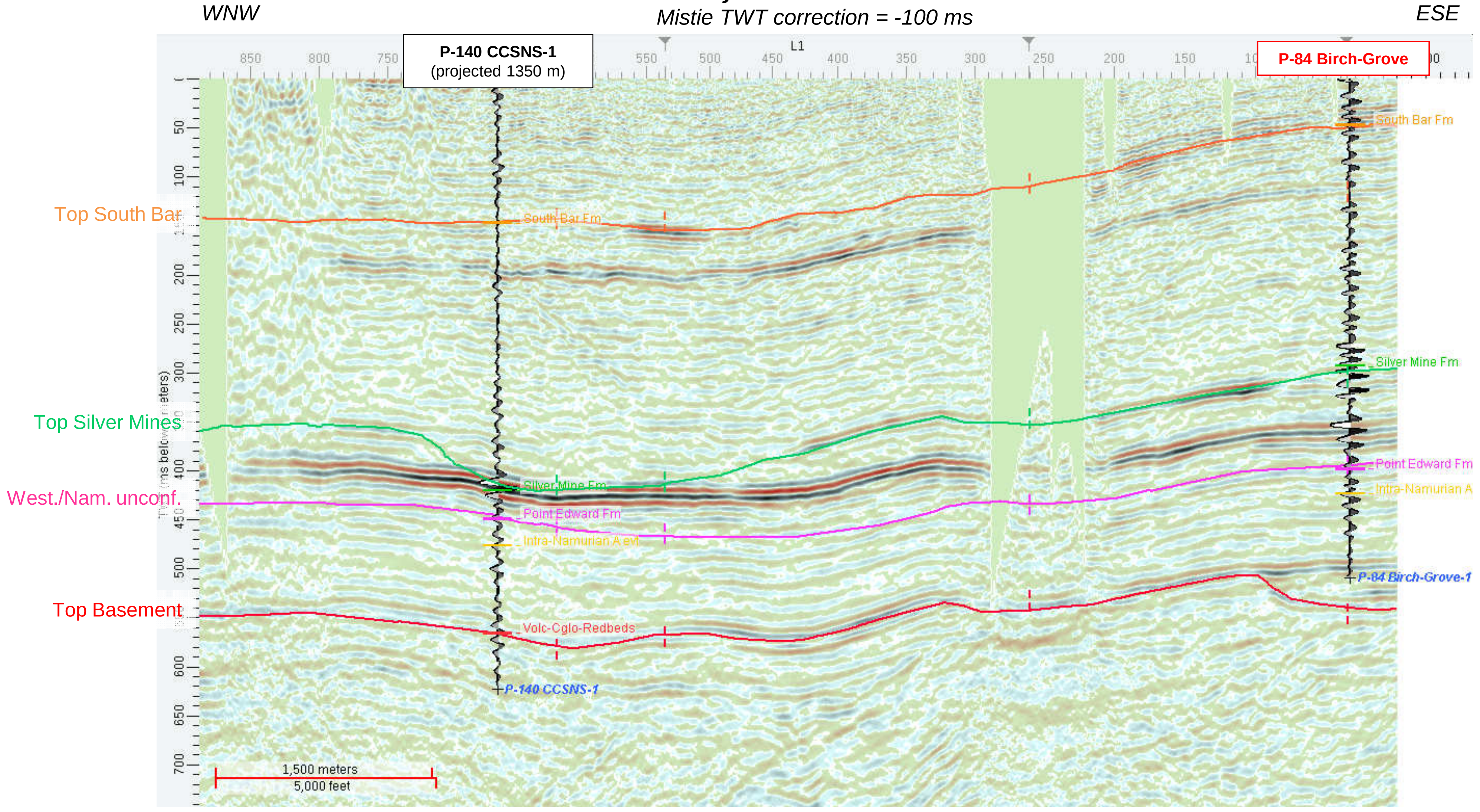
BIOSTRATIGRAPHY	RPS Energy 2017

SEISMIC LOCATION	
Survey	CCSNS 2013
Line	L1
CDP / Trace	2113 / 33
Offset (m)	220

SEISMIC MARKERS

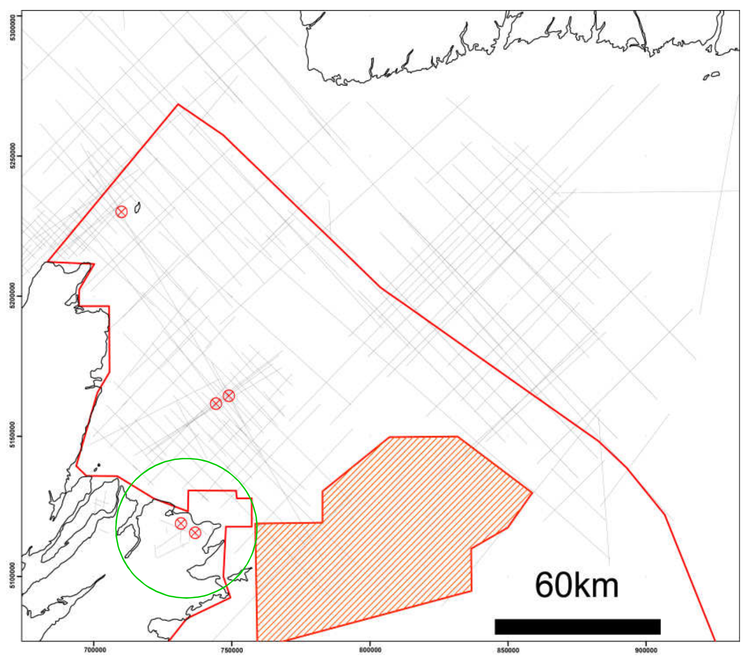
Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	*(onshore)*	*(onshore)*
309	Sydney Mine	*(no data)*	*(no data)*
313	Waddens Cove	*(no data)*	*(no data)*
315	South Bar	147	-268
320	Silver Mine	393	-794
323	Point Edward – Westphalian/Namurian unc.	523	-1012
329	Cape Dauphin	*(not reached)*	*(not reached)*
331	Woodbine Road	*(not reached)*	*(not reached)*
334	Meadows Road	*(not reached)*	*(not reached)*
339	Sydney River	*(not reached)*	*(not reached)*
360	Pre-Rift	*(not reached)*	*(not reached)*

Survey CCSNS 2013 – line L1
Mistie TWT correction = -100 ms



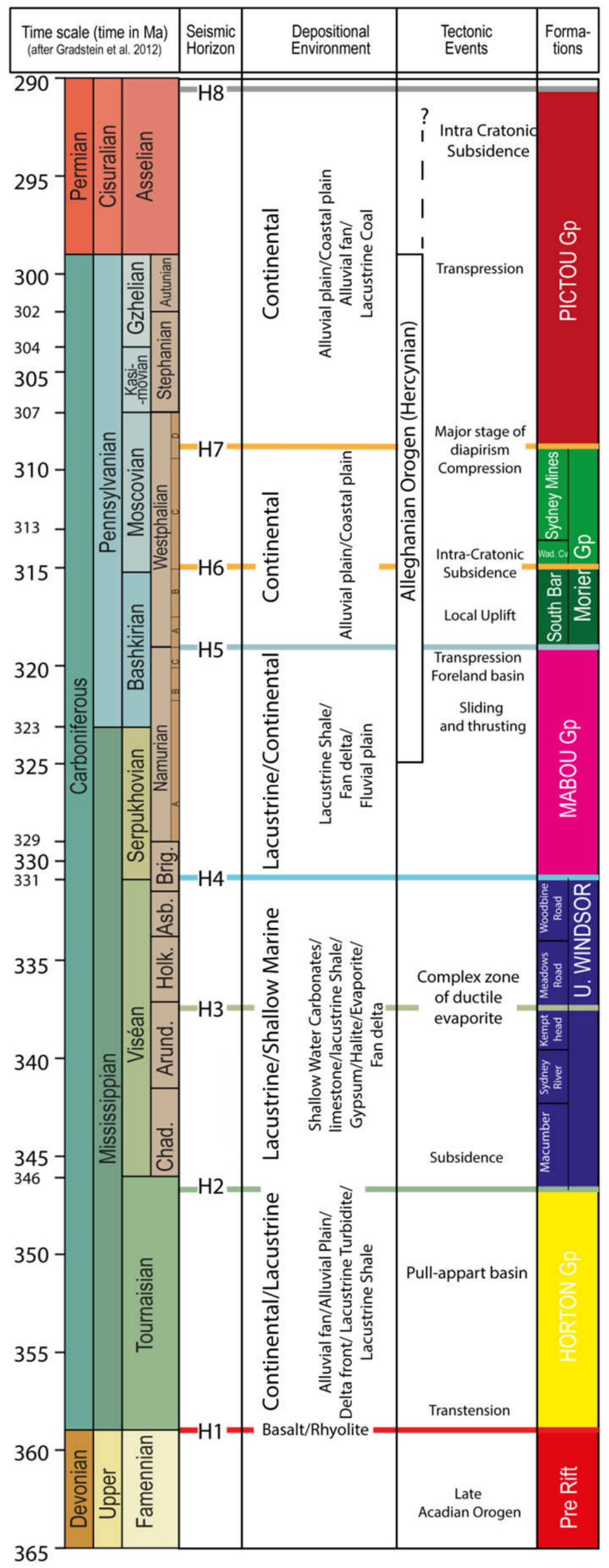
Comments

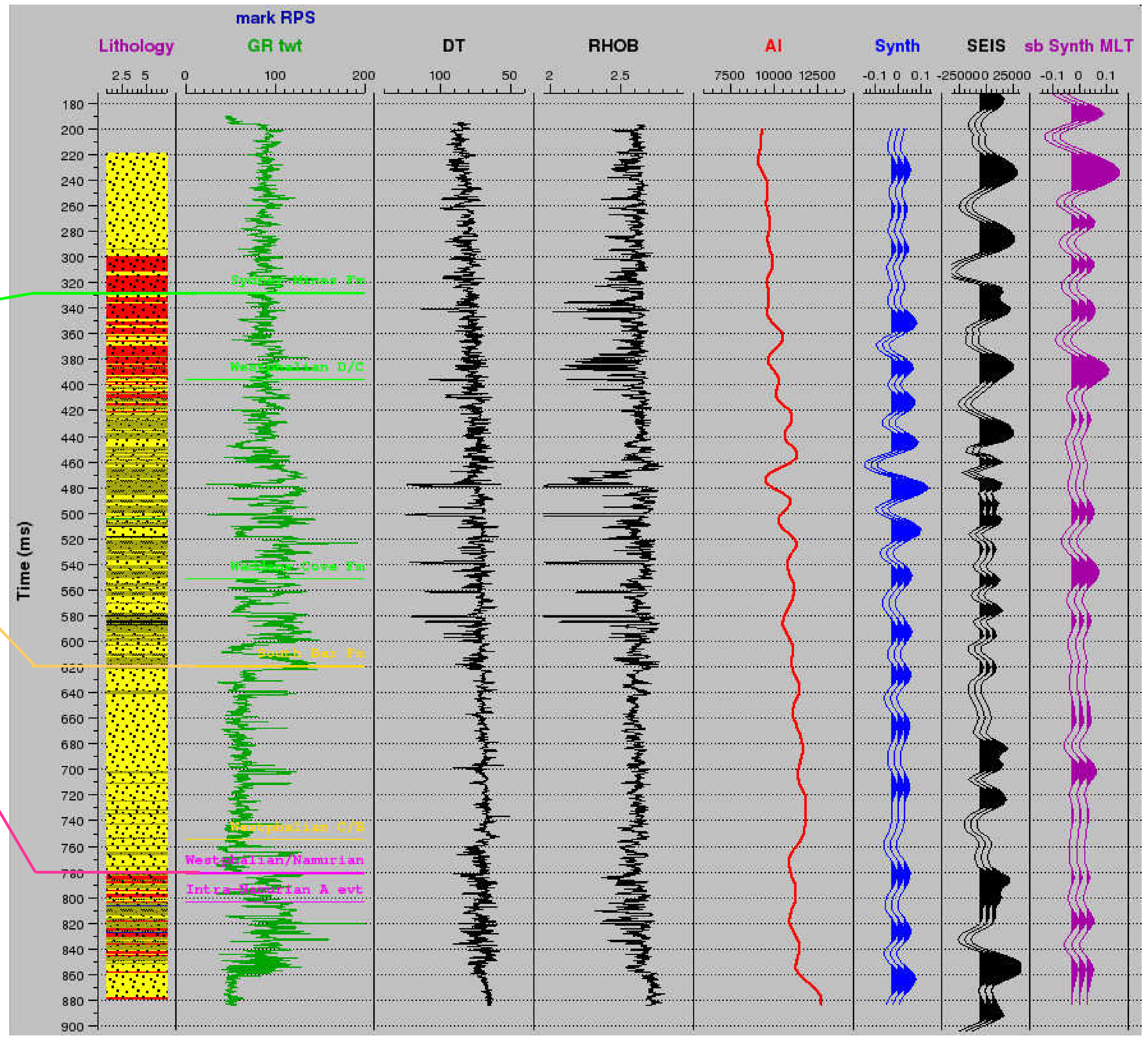
No checkshot survey was available. It was not possible to create a confident visual match without an independent time/depth curve.
Final calibration was aided by extrapolating ties from P-140 (the horizons are easily extended from P-140 to P-84)



Birch-Grove-1 P-84

SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION





Initial T/D relationship from sonic integration **corrected with checkshot data**
Synthetic trace 'MLT' computed with IBMM – Inter Bed Multiple Modeling – option in EasyTrace™
Added TWT shift for synthetic calibration: -33 ms

WELL HEADER

Well Name	**North-Sydney F-24**	
Rotary Table (R.T.)	29.7 m	
Total Depth (T.D.)	1706 m (MD R.T.)	
Geographic coordinates @surface (NAD27)	Lat: 43° 36' 17.98" N	Lon: 60° 39' 56.29" W
UTM coordinates (NAD27, Zone 20N)	X_{UTM} : 744320	Y_{UTM} : 5160592

BIOSTRATIGRAPHY	RPS Energy 2017

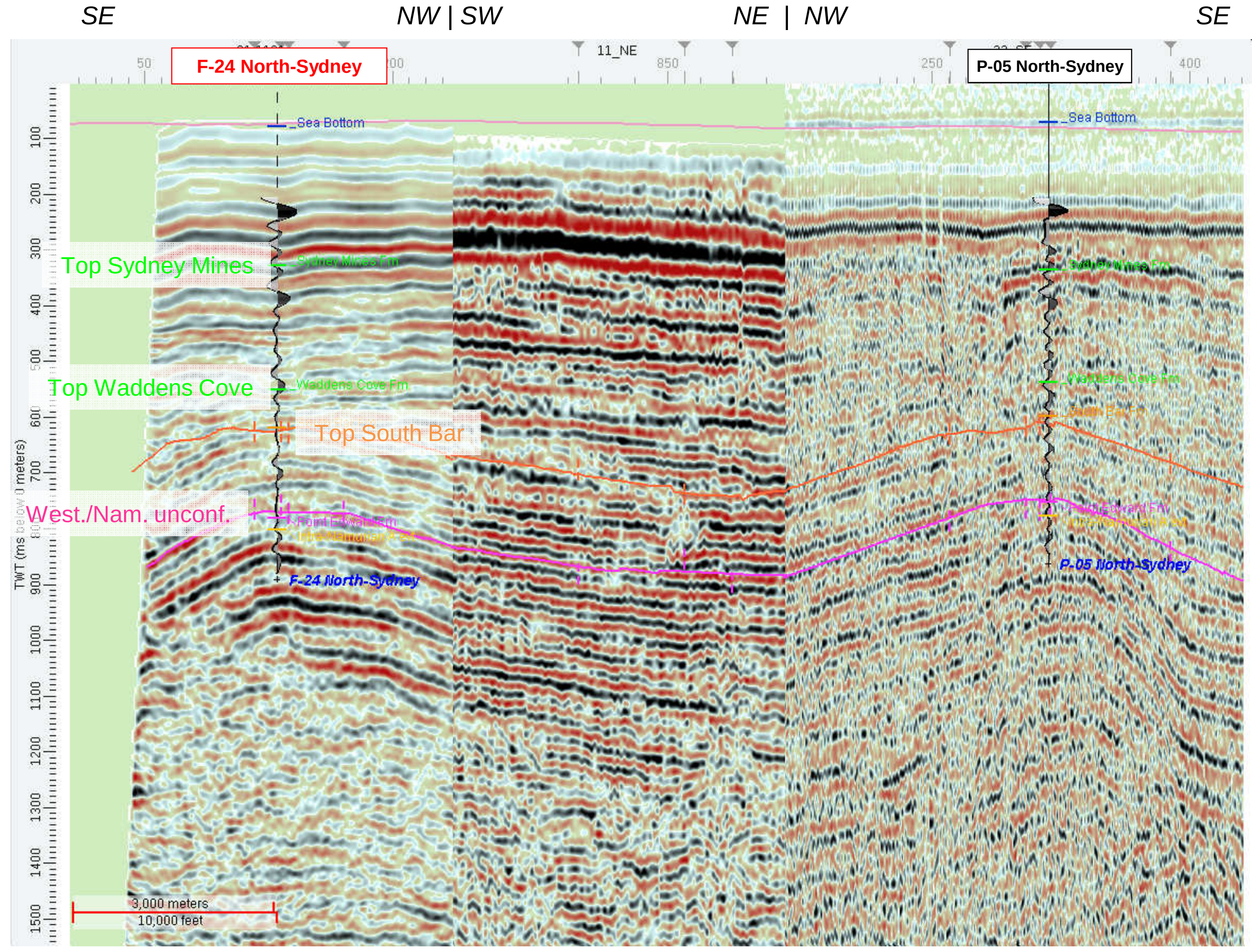
SEISMIC LOCATION

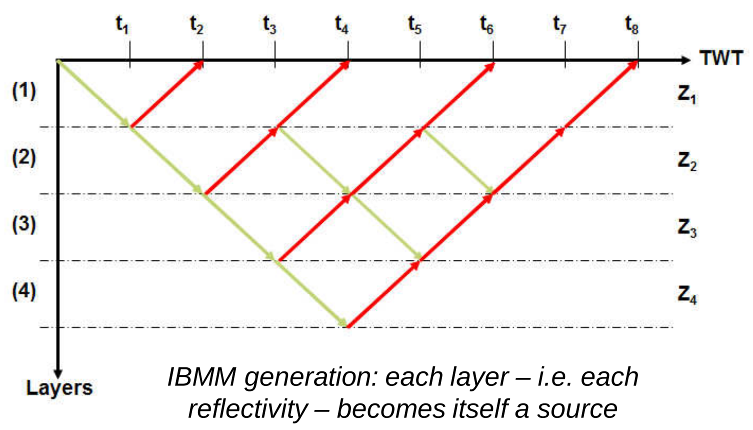
Survey	PetroCanada 1981
Line	81-1121
CDP / Trace	336 / 130
Offset (m)	160

SEISMIC MARKERS

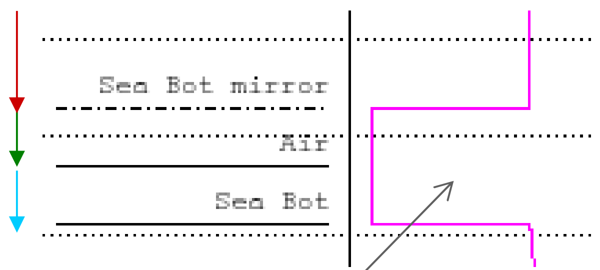
Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	82	-59
309	Sydney Mine	329	-492
313	Waddens Cove	552	-918
315	South Bar	620	-1055
320	Silver Mine	*(not present)*	*(not present)*
323	Point Edward – Westphalian/Namurian unc.	781	-1406
329	Cape Dauphin	*(not reached)*	*(not reached)*
331	Woodbine Road	*(not reached)*	*(not reached)*
334	Meadows Road	*(not reached)*	*(not reached)*
339	Sydney River	*(not reached)*	*(not reached)*
360	Pre-Rift	*(not reached)*	*(not reached)*

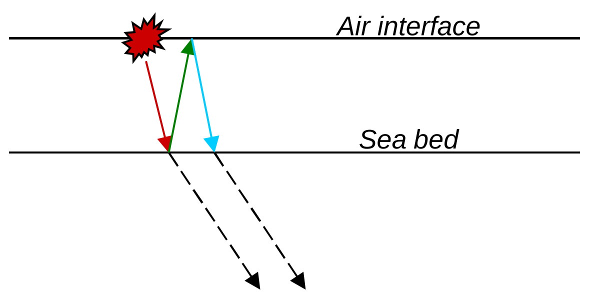
Survey PetroCanada 1981 – 81-1121



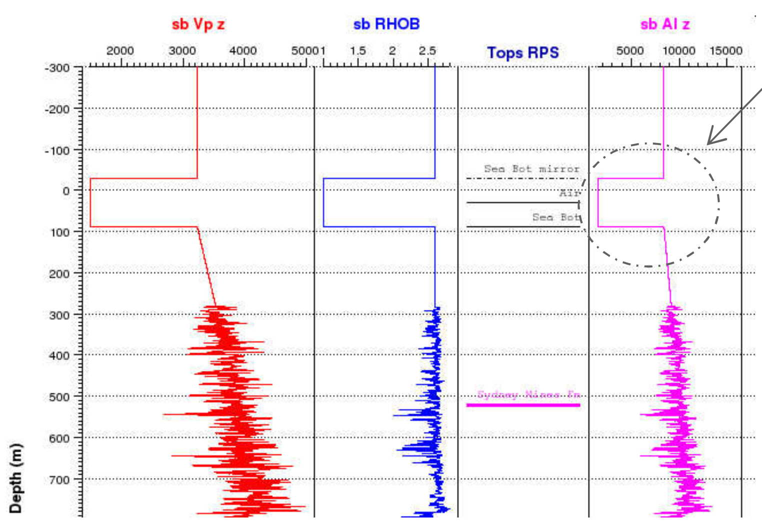


IBMM generation: each layer – i.e. each reflectivity – becomes itself a source

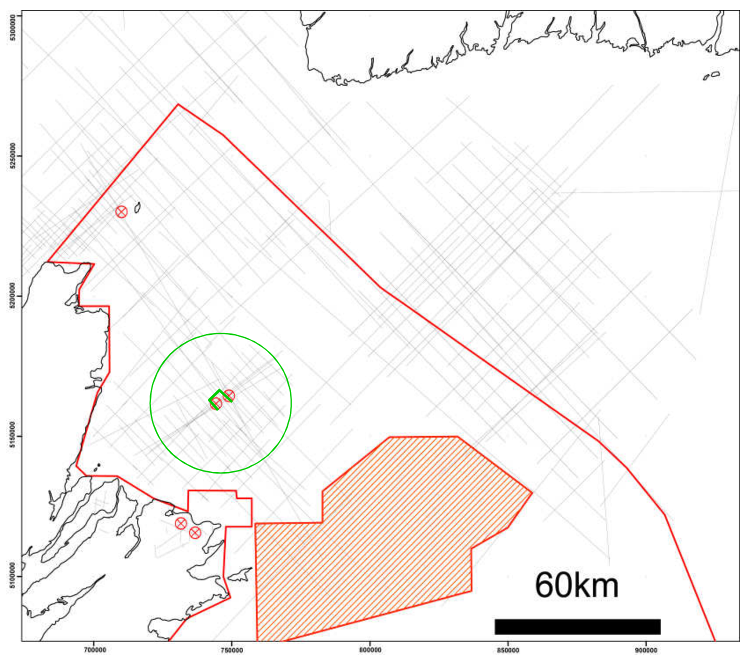




Initialization of the first peg-leg in the sea layer through a sea bottom mirror reflectivity



Extension of the velocity and density logs upwards, then creation of the double sea bottom reflectivity

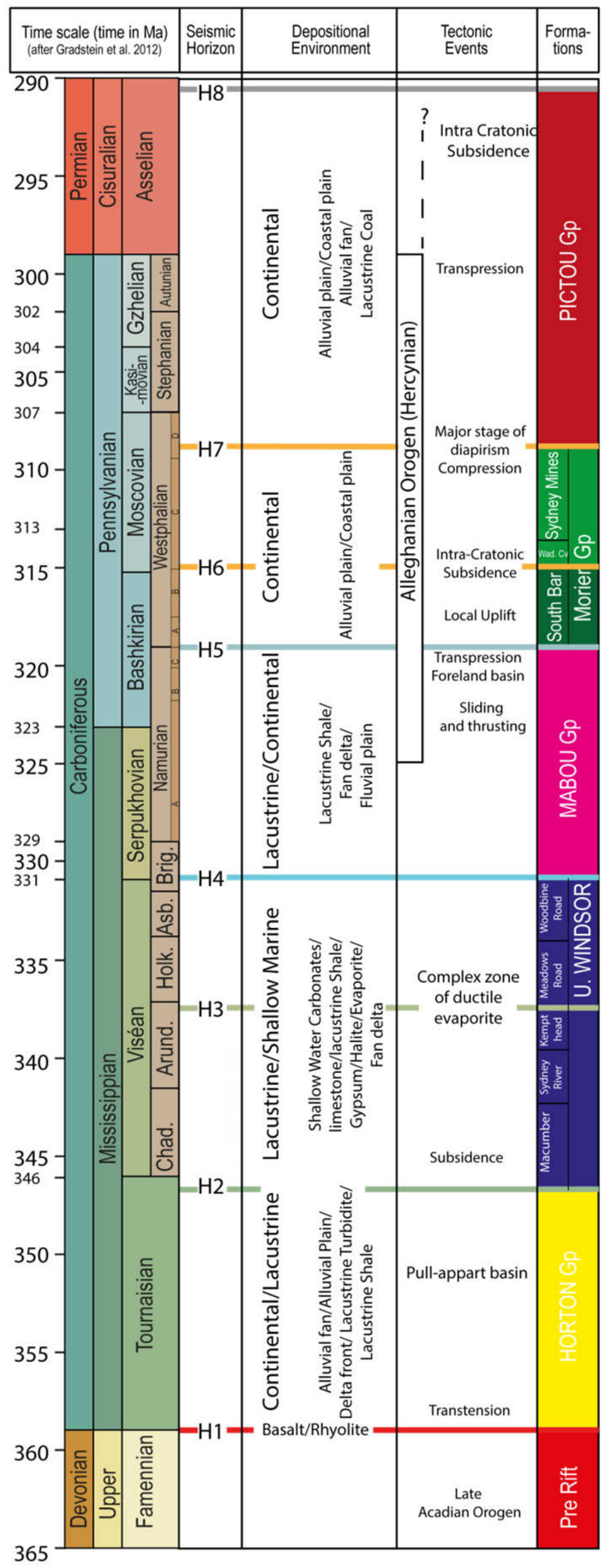


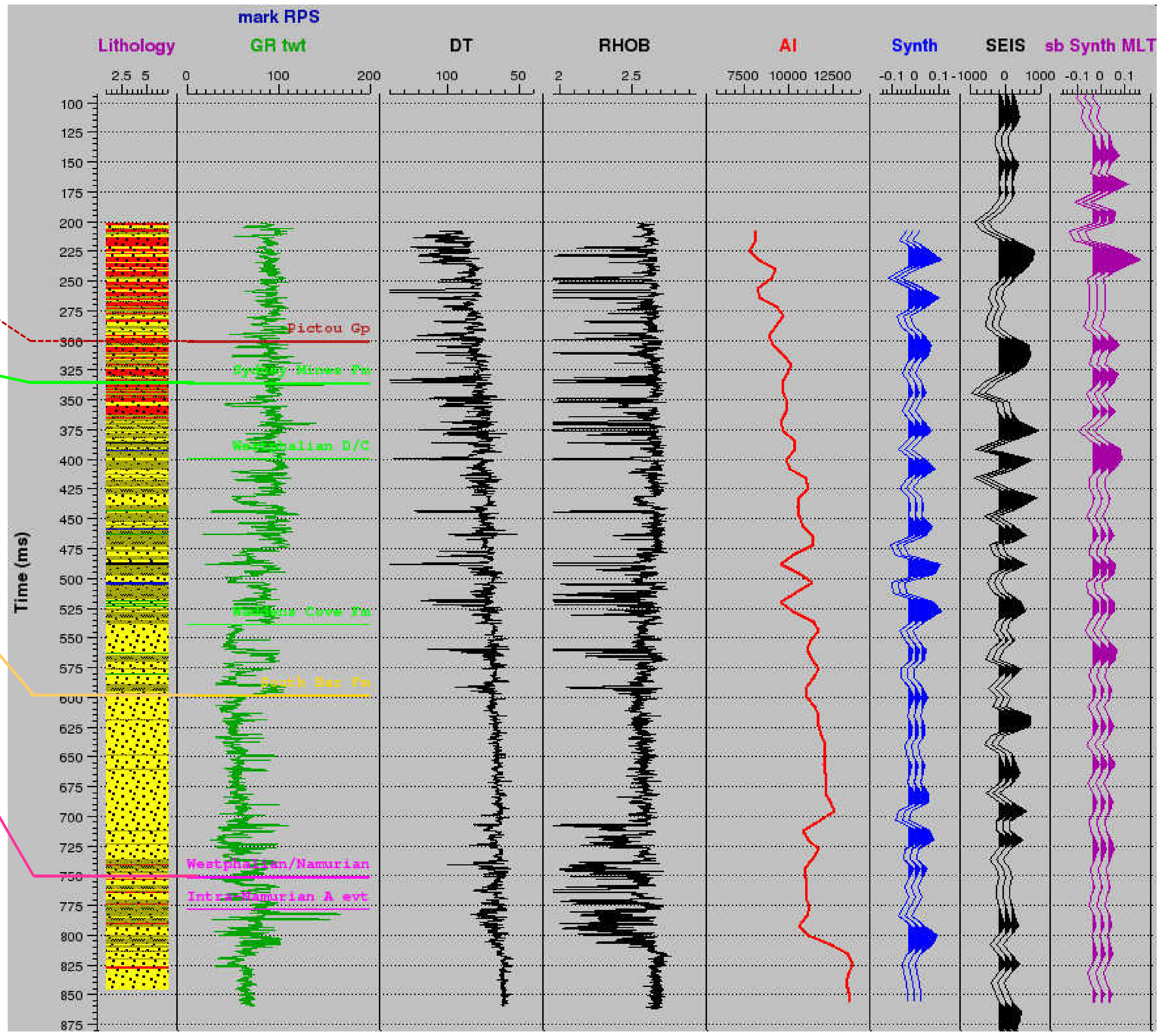
Comments

A checkshot survey was available
Strong multiples are observed at shallow depth, preventing the use of the classic primaries leaving only synthetic (blue in the log panel). A reflectivity with IBMM (*internal bedding multiple modeling*) option was created in *EasyTrace*™ by using a pre seabed layer simulating the first peg-leg in the marine layer and initializing the IBMM.

The calibration of F-24 (well on the left of the section) was achieved using the synthetic with multiples (in purple in the log panel and along the well path in the section). The final adjustment was done with the help of P-05's calibration and the easy propagation of the horizons.

SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION





Initial T/D relationship from sonic integration ***corrected with checkshot data***
Synthetic trace 'MLT' computed with IBMM – Inter Bed Multiple Modeling – option in EasyTrace™
Added TWT shift for synthetic calibration: -16 ms

WELL HEADER

Well Name	**North-Sydney P-05**	
Rotary Table (R.T.)	29.9 m	
Total Depth (T.D.)	1661 m (MD R.T.)	
Geographic coordinates @surface (NAD27)	Lat: 43° 36' 17.98" N	Lon: 60° 39' 56.29" W
UTM coordinates (NAD27, Zone 20N)	X_{UTM} : 748976	Y_{UTM} : 5163351

BIOSTRATIGRAPHY

BIOSTRATIGRAPHY	RPS Energy 2017

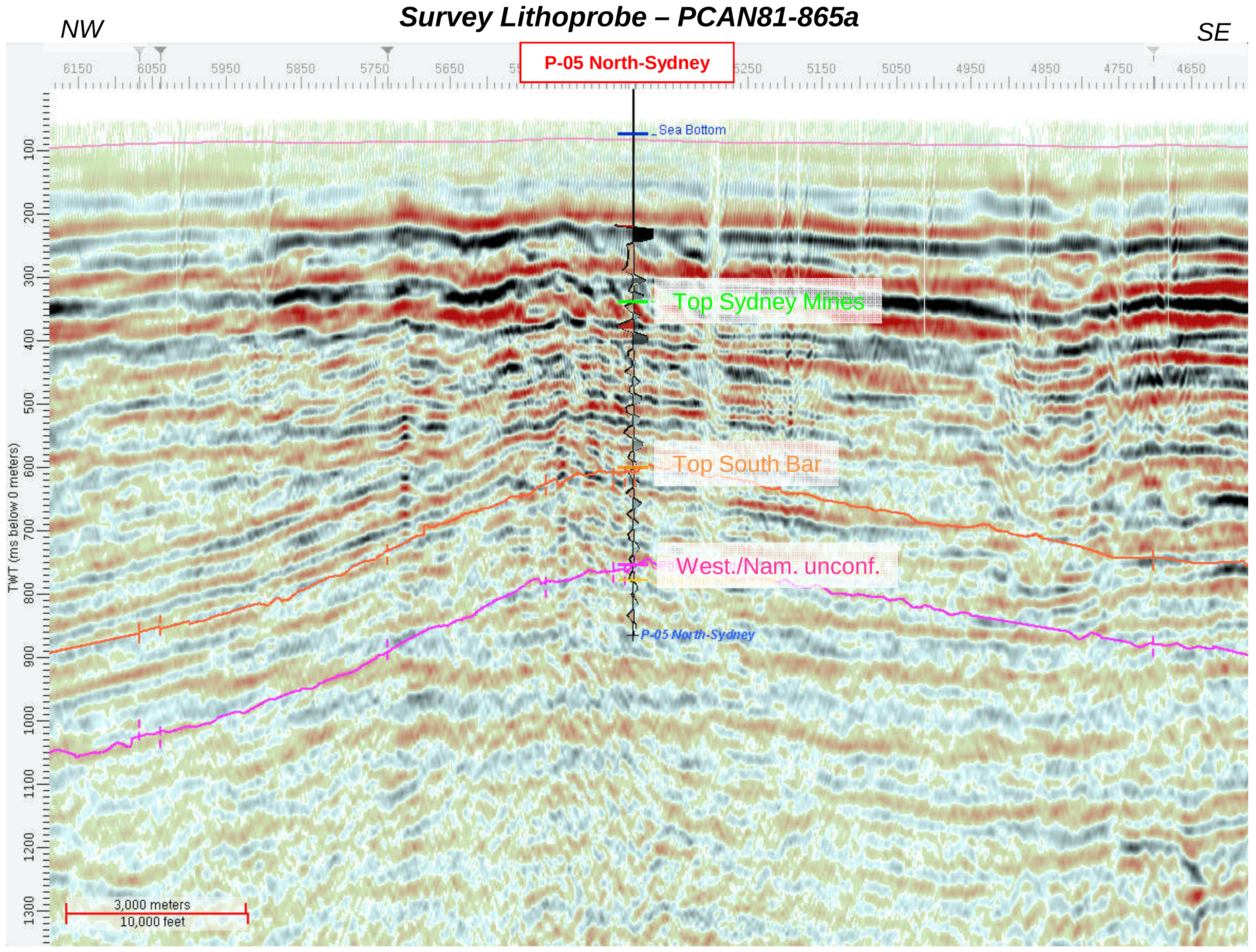
SEISMIC LOCATION

Survey	Lithoprobe
Line	PCAN81-865a
Trace	5404
Offset (m)	50

SEISMIC MARKERS

Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	74	-63
309	Sydney Mine	337	-499
313	Waddens Cove	539	-887
315	South Bar	599	-1016
320	Silver Mine	*(not present)*	*(not present)*
323	Point Edward – Westphalian/Namurian unc.	752	-1363
329	Cape Dauphin	*(not reached)*	*(not reached)*
331	Woodbine Road	*(not reached)*	*(not reached)*
334	Meadows Road	*(not reached)*	*(not reached)*
339	Sydney River	*(not reached)*	*(not reached)*
360	Pre-Rift	*(not reached)*	*(not reached)*

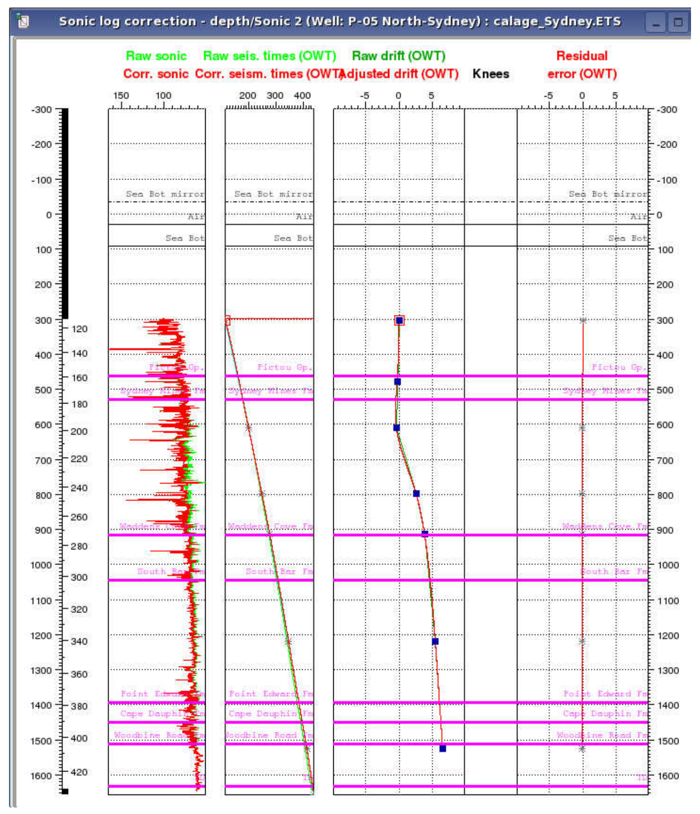
Survey Lithoprobe – PCAN81-865a



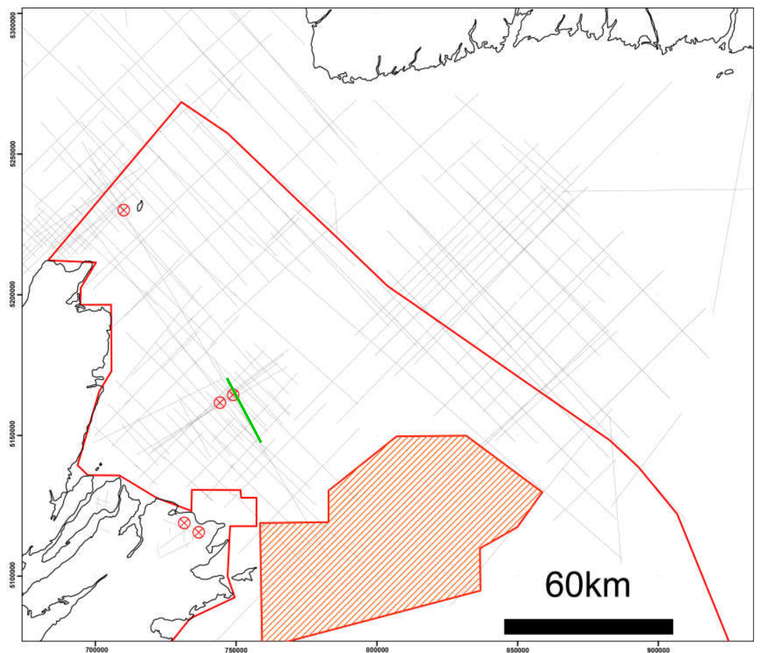
Comments

A checkshot survey was available
Very strong multiples exist in the shallow levels, preventing the use of the classic primaries leaving only synthetic (blue in the log panel). A reflectivity with IBMM (*internal bedding multiple modeling*) option was created in *EasyTrace™* by using a pre seabed layer simulating the first peg-leg in the marine layer and initializing the IBMM edit as for F24 (see PL. 5.2.1.3 for details).

The calibration of P-05 was achieved using the synthetic with multiples (in purple in the log panel and along the well path in the section).

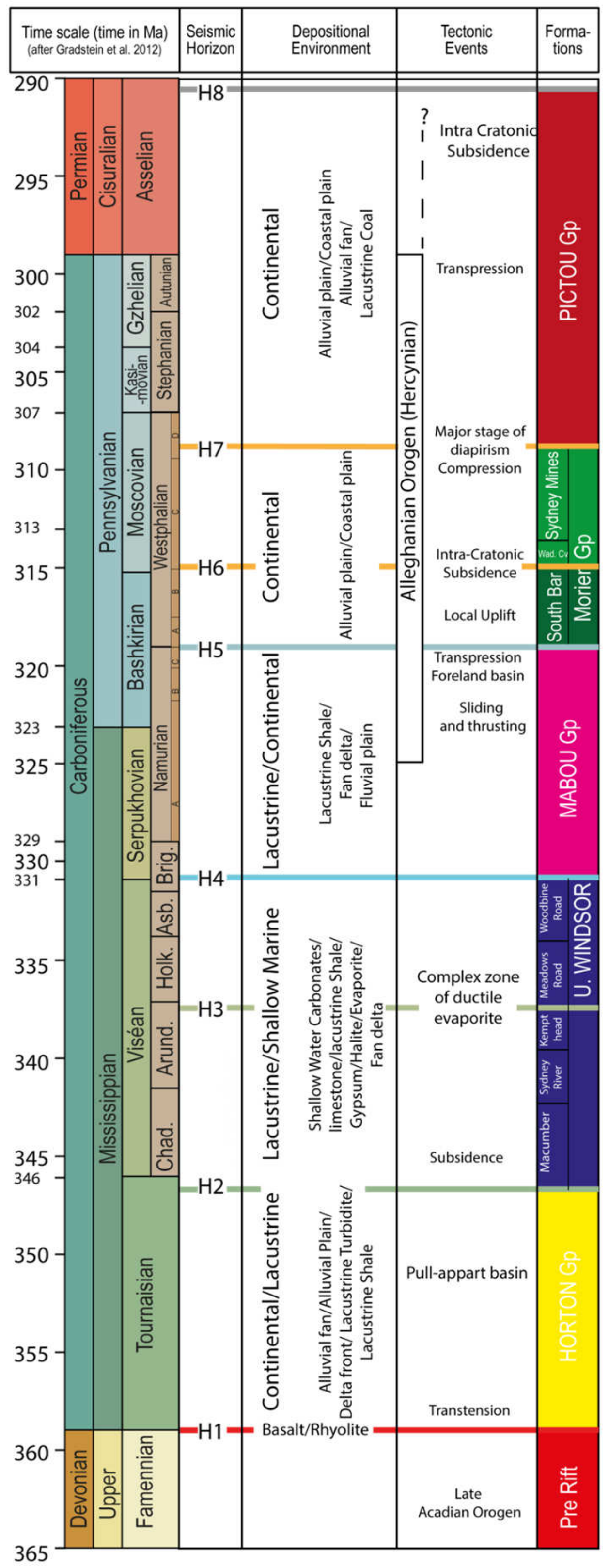


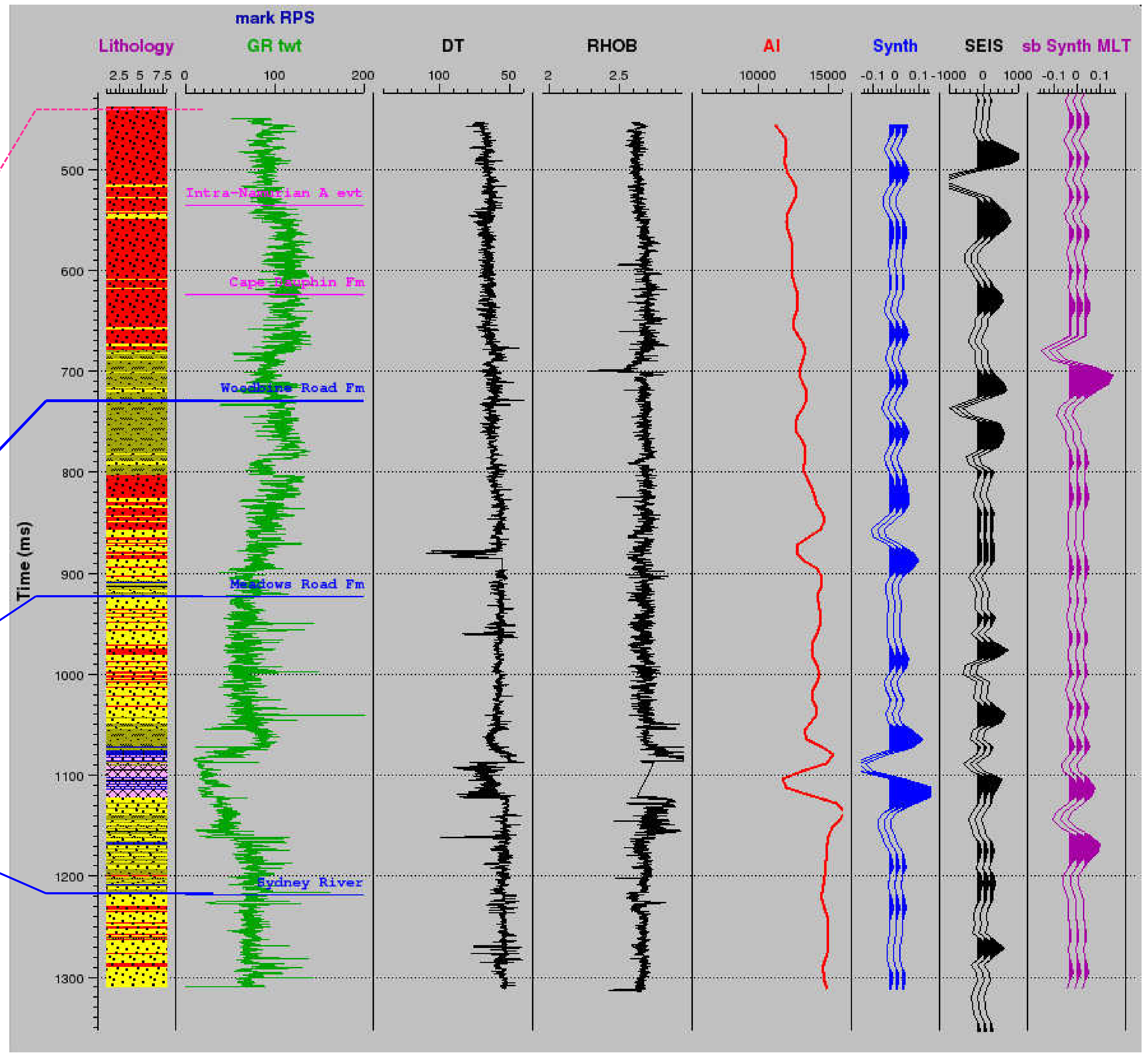
Correction of the sonic drift (< 7 ms) through check shots



North-Sydney P-05

SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION





*Initial T/D relationship from sonic integration **corrected with checkshot data***
Synthetic trace 'MLT' computed with IBMM – Inter Bed Multiple Modeling – option in EasyTrace™
No added TWT shift for synthetic calibration (no fair correlation)

WELL HEADER		
Well Name	**Saint-Paul P-91**	
Rotary Table (R.T.)	25.2 m	
Total Depth (T.D.)	2880 m (MD R.T.)	
Geographic coordinates @surface (NAD27)	Lat: 43° 36' 17.98" N	Lon: 60° 39' 56.29" W
UTM coordinates (NAD27, Zone 20N)	X_{UTM} : 710107	Y_{UTM} : 5228985

BIOSTRATIGRAPHY	RPS Energy 2017

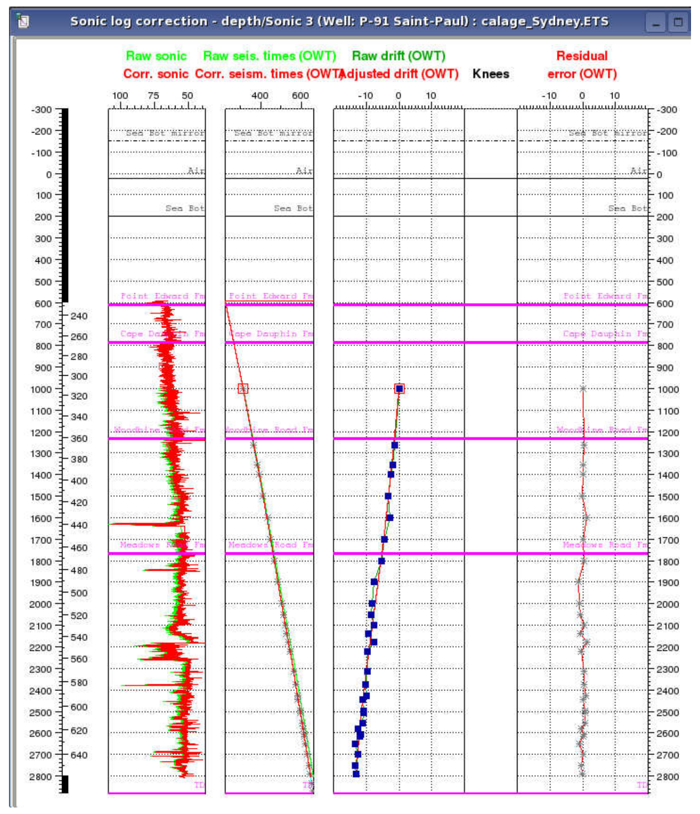
SEISMIC LOCATION		
Survey	Lithoprobe	
Line	PCAN81-865a	
Trace	11487	
Offset (m)	30 @ well head	350 @ T.D.

SEISMIC MARKERS

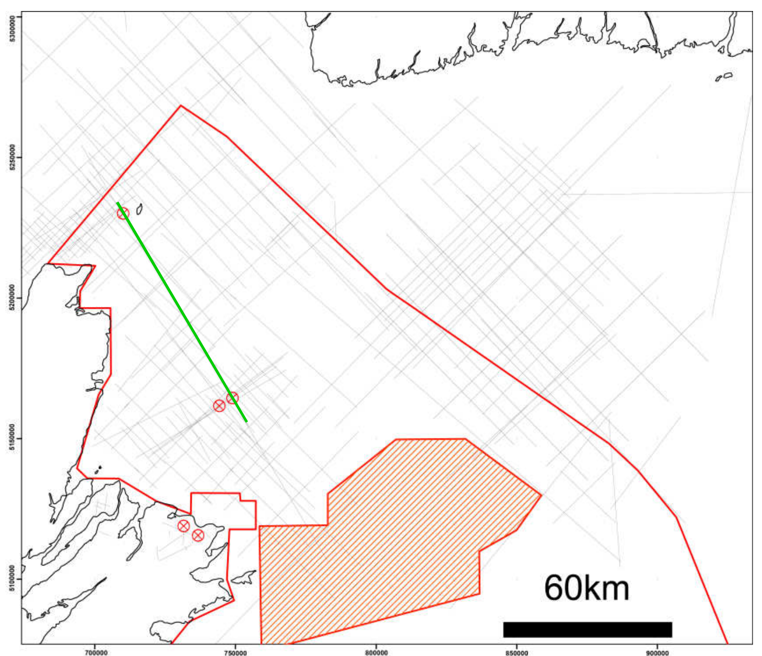
Age (Ma)	Name	ms (TWT)	m (TVDSS)
0	Seabed	74	-173
309	Sydney Mine	*(no data)*	*(no data)*
313	Waddens Cove	*(no data)*	*(no data)*
315	South Bar	*(no data)*	*(no data)*
320	Silver Mine	*(no data)*	*(no data)*
323	Point Edward – Westphalian/Namurian unc.	*(above 461)*	*(above -584)*
329	Cape Dauphin	624	-960
331	Woodbine Road	730	-1221
334	Meadows Road	923	-1715
339	Sydney River	1219	-2516
360	Pre-Rift	*(not reached)*	*(not reached)*

Comments

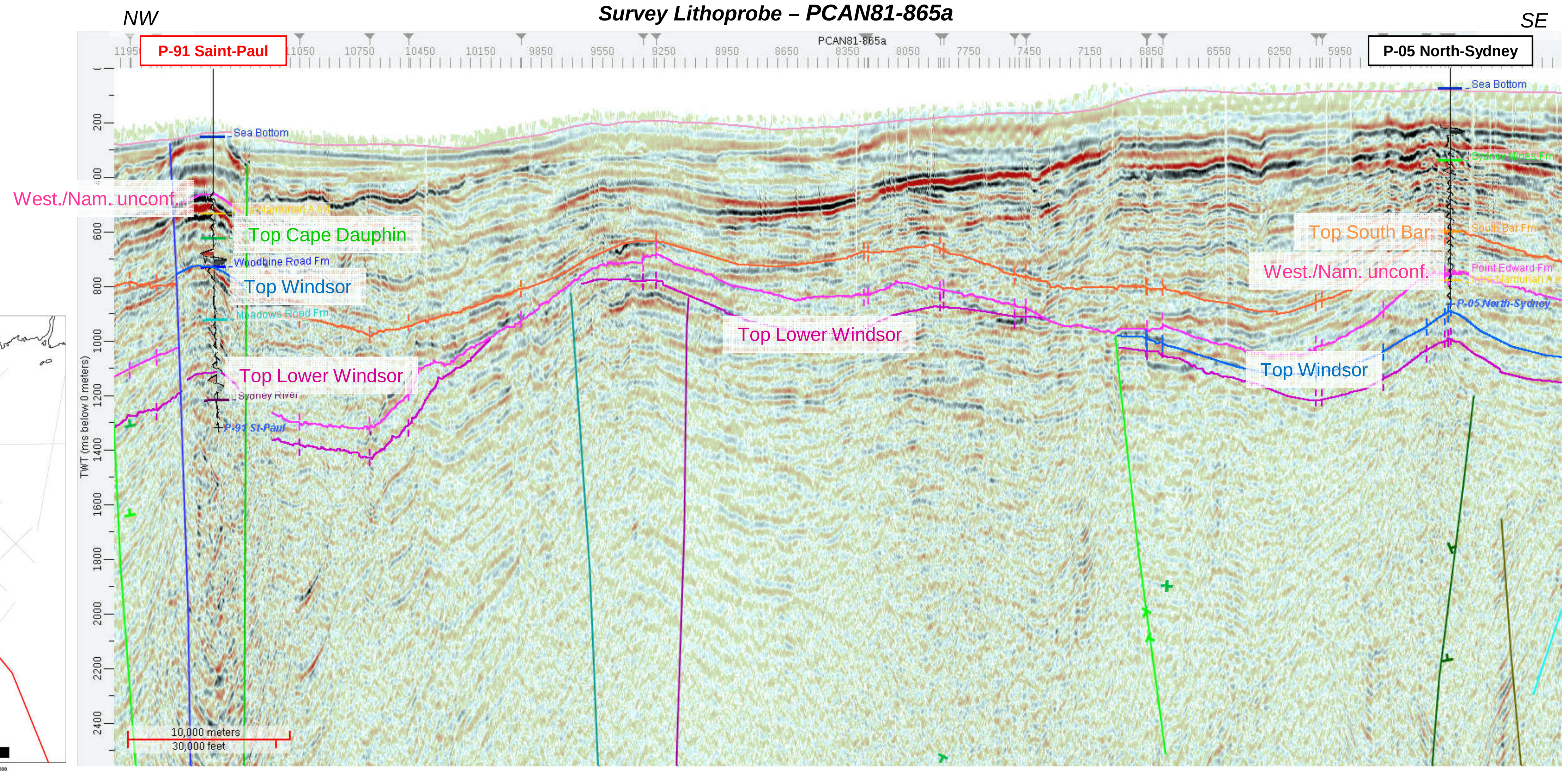
A checkshot survey was available.
The seismic part of Cabot high where P-91 was drilled (well on the left of the section), is almost exclusively composed of major multiples of the sea bed and a shallow strong erosion, preventing any calibration with a synthetic. The true impedance changes – expected to be strong in this well due to the erosion – are unknown in the shallowest parts of the well, preventing a good modeling of the reflectivity with internal peg-legs (see PL. 5.2.1.3 for details). The well calibration was done with the checkshot values only. A second indirect validation is the tie of the Seabed marker with the Seabed horizon.



Correction of the sonic drift (< 13 ms) through checkshots



Survey Lithoprobe – PCAN81-865a



Definition and interpretation of the shallow horizons

Wells F-24 and P-05 are the only ones where it is possible to tie the shallow horizons, i.e.:

- Westphalian/Namurian Unconformity (equivalent to top Point Edward at the wells);
- Top South Bar;
- any shallower horizon.

The seismic vintages show significant differences in terms of frequency, quality, polarity, and even residual 2D misties, and so it is difficult to assign a seismic feature – maximum, minimum or zero-crossing of a seismic event – to any horizon. Only the Westphalian/Namurian Unconformity can be easily followed and recognized on some of the PetroCanada 1981 lines. The tie-up of these horizons is shown in PL. 5.2.1.3 and -.5.2.1.4

Definition and interpretation of the deep horizons

Horizons deeper than Top Mabou (=Westphalian/Namurian Unconformity) are present in P-91 (Windsor Fm.) and CCNS-1 (Top Basement), but the location of the wells makes it difficult to the extrapolate these horizons:

- It is difficult to extrapolate the deep levels across the Cabot major faults (P-91 isolated on a high);
- It is difficult to follow the horizons across the onshore/offshore break (no continuous line and severe multiples).

Therefore, the lower series were directly defined from the seismic character, in the following order:

(a) Top Lower Windsor: defined as top of a salt pillow encountered in line F of 8624-T007-006E survey (see Figure 1 to illustrate the case for this pick);

(b) Top Windsor: the synthetic traces in the wells show that the Windsor Formation has a much stronger reflectivity than the overlying Mabou Formation which is rather quiet (Figure 2). Scanning the 2010 survey lines (best quality in the study area), a frank limit of seismic feature is always present between the Westphalian/Namurian Unconformity and the Top Lower Windsor. Located between the first third and the half of this defined layer, it separates a weak energy sub-layer overlying strong seismic events (blue ellipses in Figure 3 and 4, labelled as “strong events”), whose onset was defined as Top Windsor;

(c) Top Horton: as with the basement, it was mainly picked on 2010 survey lines as presented below (Figure 2 - Lines 6 and 22). A seismic facies inferred to be typical Horton facies has been observed above the basement on line I of the 8624-T007-006E survey (see PL. 5.3.2.3);

(d) Top Basement: as with the Horton, it is mainly visible on the 2010 survey lines. It is clearly defined as a major angular unconformity, typically structured in tilted blocks in some of the clear lines presented below.

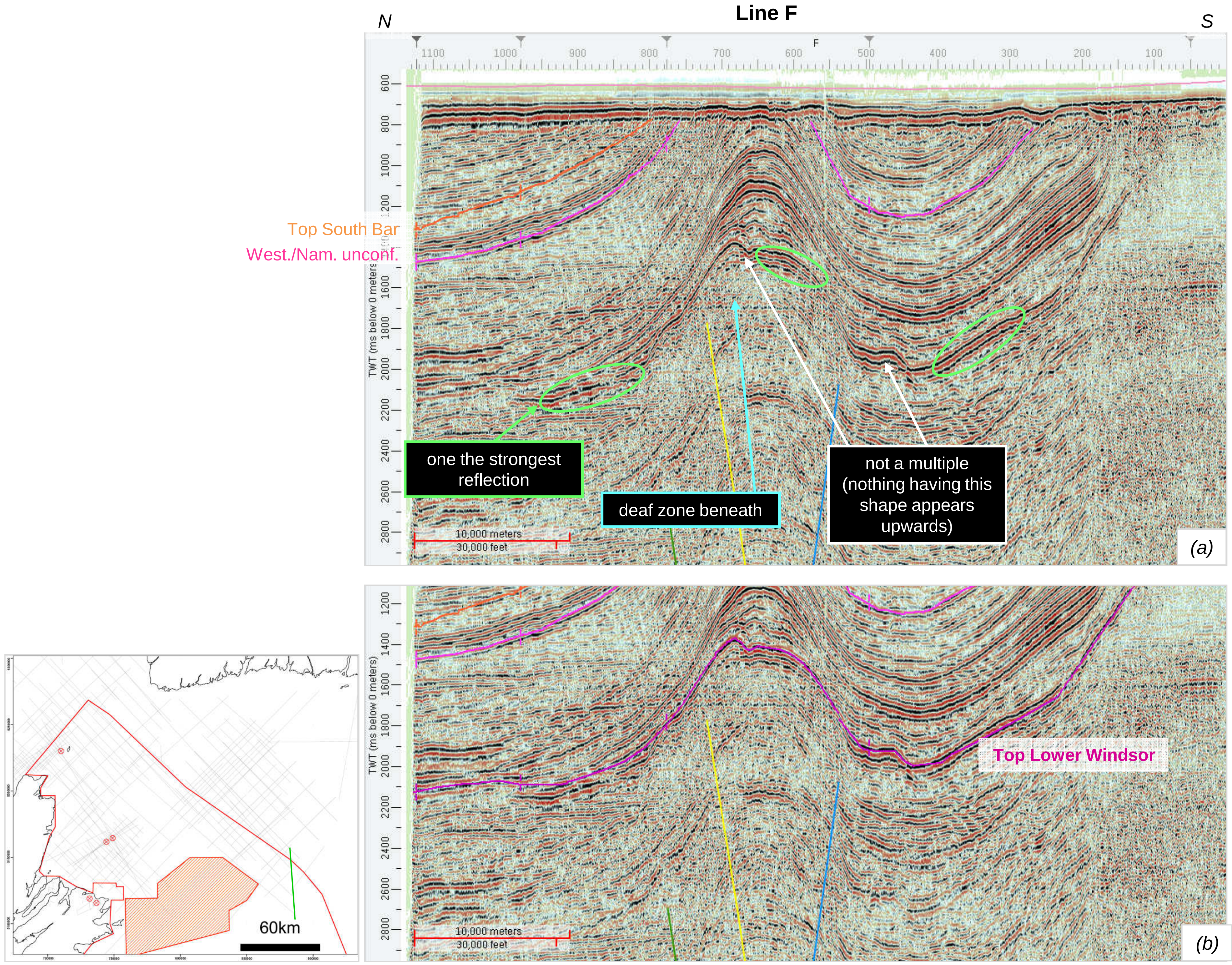


Figure 1: (a) Definition of top Lower Windsor from seismic pattern as top of the salt pillow in line F – (b) Its picking

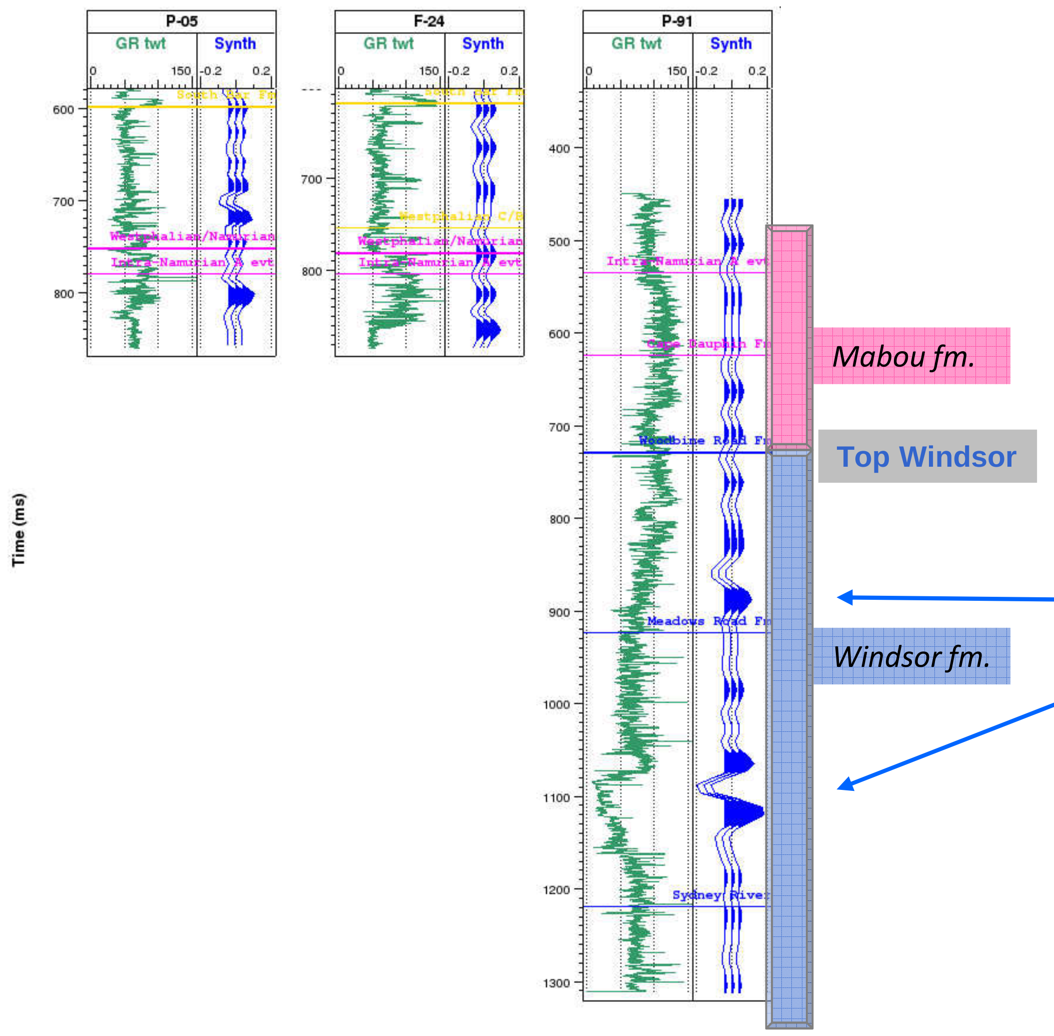


Figure 2: Stronger reflectivity in Windsor than Mabou Fm.

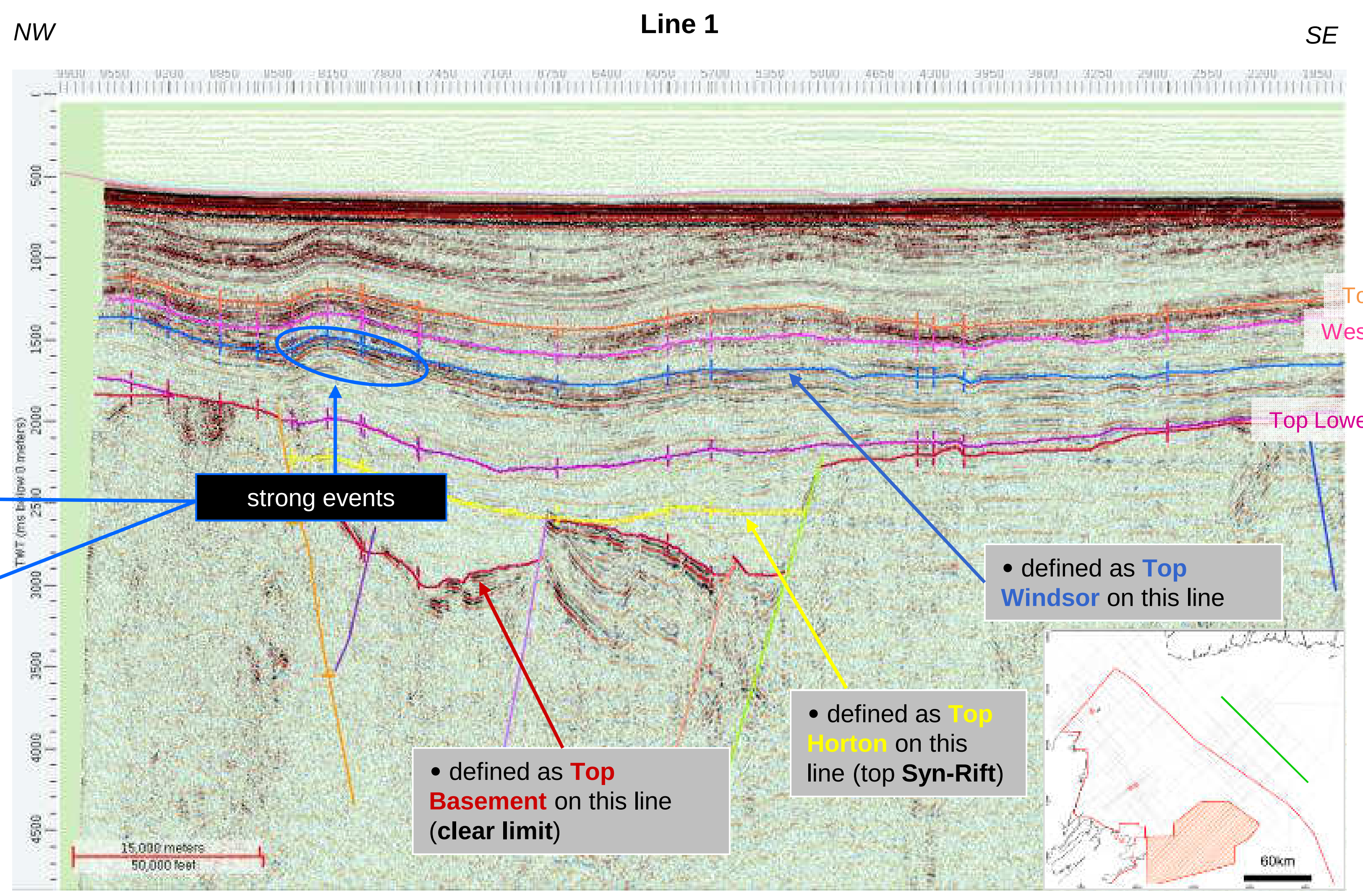


Figure 3: Definition of 3 horizons on Line 1

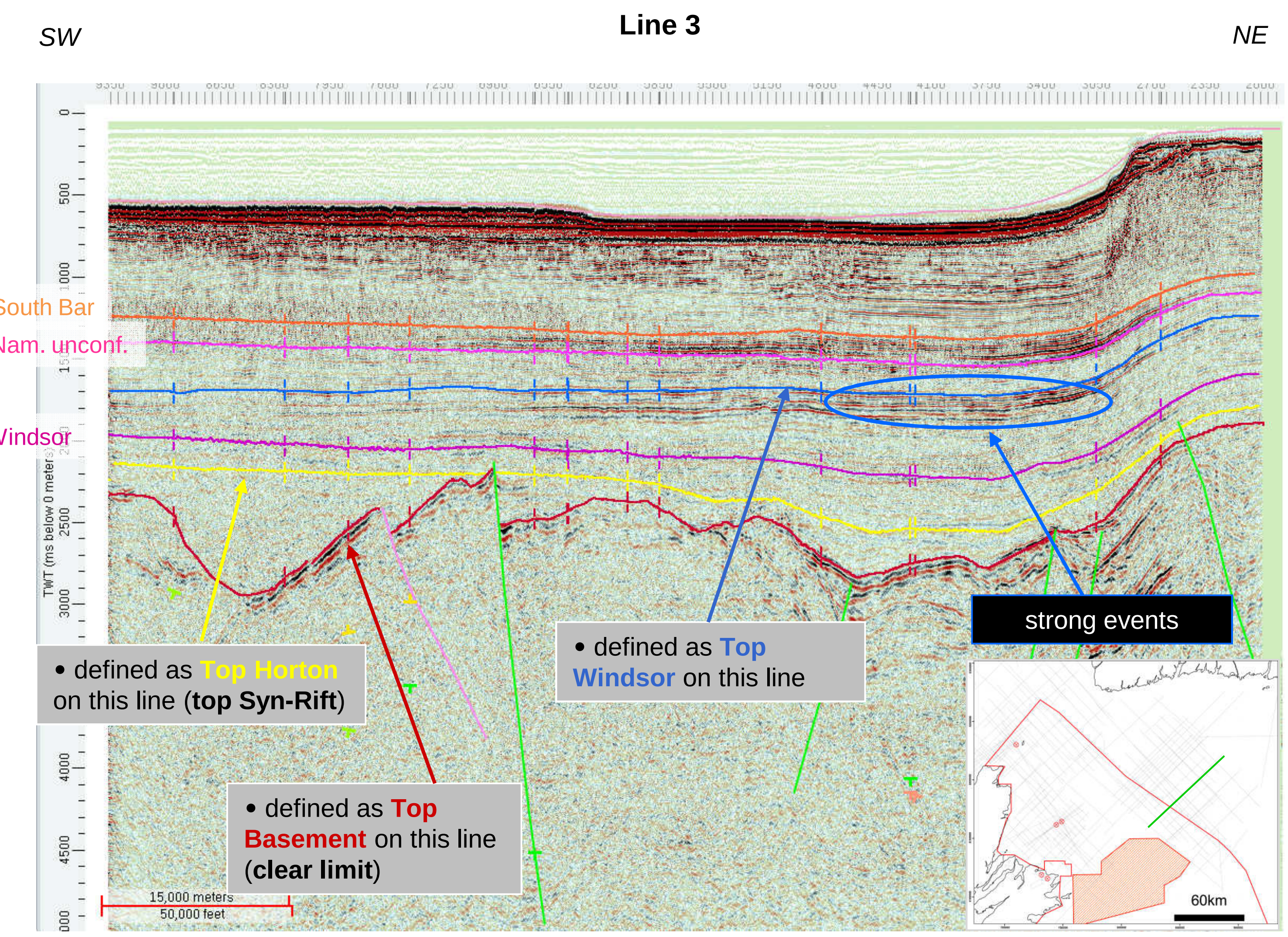
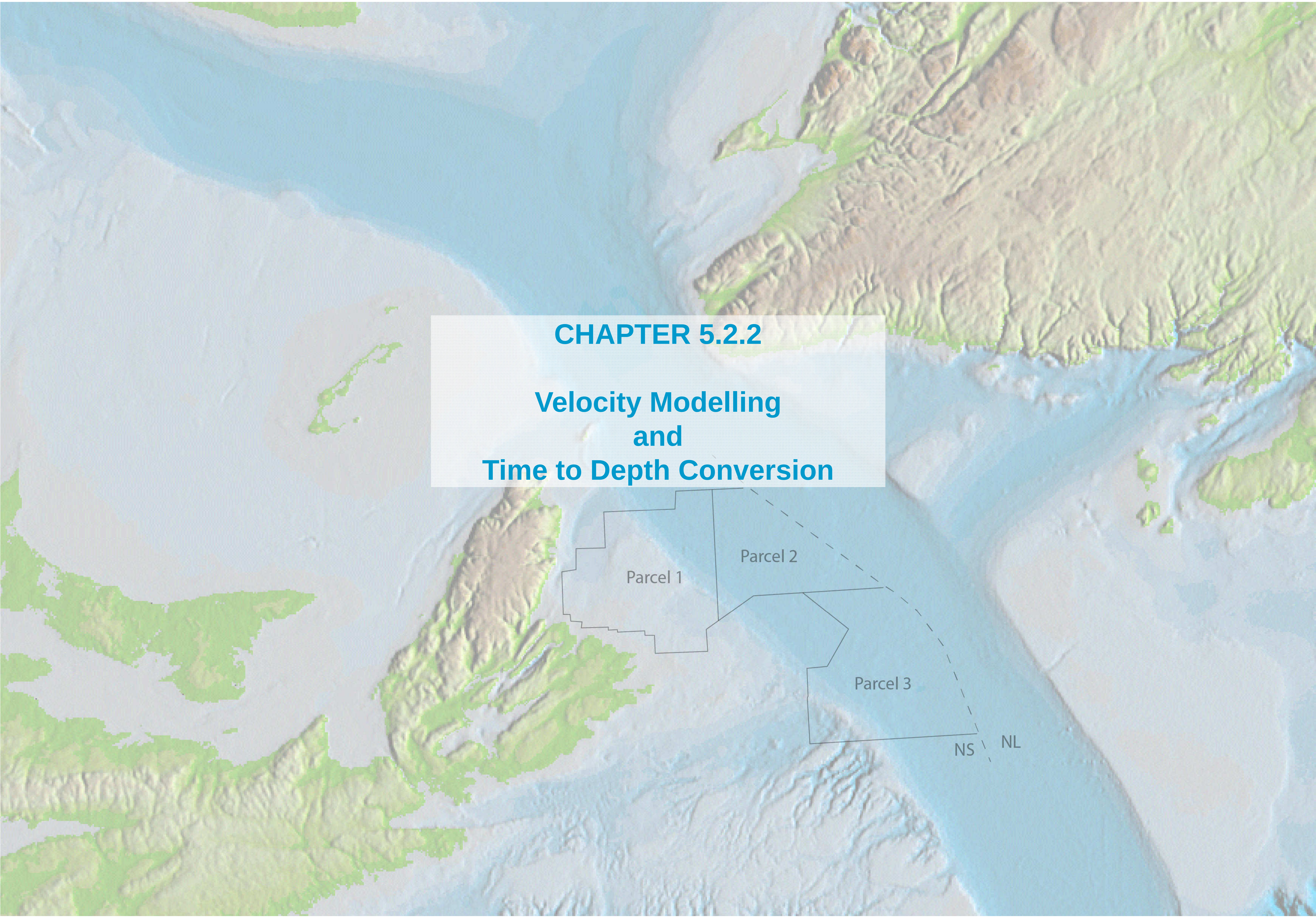


Figure 4: Definition of 3 horizons on line 3

CHAPTER 5.2.2

Velocity Modelling and Time to Depth Conversion



Velocity Modeling

A 3D velocity model was built within the survey area to obtain a time (TWT) to depth (Zss) conversion model. As no seismic velocity was available, we used the original velocity data from the 3 offshore wells (Figure 1), the sonic drift < 10 ms being negligible. F-24 and P-05 are very close and P-91 is isolated on the Cabot structural high. Their specific locations are unsuited for simple velocity interpolation and extrapolation.

To build the velocity model, an analytic approach was attempted: assessment of analytic laws as functions of the burial. When plotted in depth (or time), the velocity increases with the compaction (Step 1a), but requires first of all correction for the water column effect (Step 1b – Figure 2). Additionally, velocities at P-91 are high due to the effect of an initial compaction prior exhumation of the Cabot structure. Therefore P-91's velocity must be corrected for the burial (Step 1c - Figure 3).

Binomial regressions were extracted and joined together (Step 2) before inputting them into *DecisionSpace Desktop* (Step 3).

[*NB: all velocities are labelled in meters/second*]

First Step: Velocity Log Preparation

(a) Computation of the smoothed interval velocities from the sonic logs (Figure 1 in red);
(b) Referencing of the logs to True Vertical Depth from Sea Bed (TVD SSB – Figure 2);
(c) Referencing of P-91's log to equivalent burial state as for the two other wells (Figure 3).

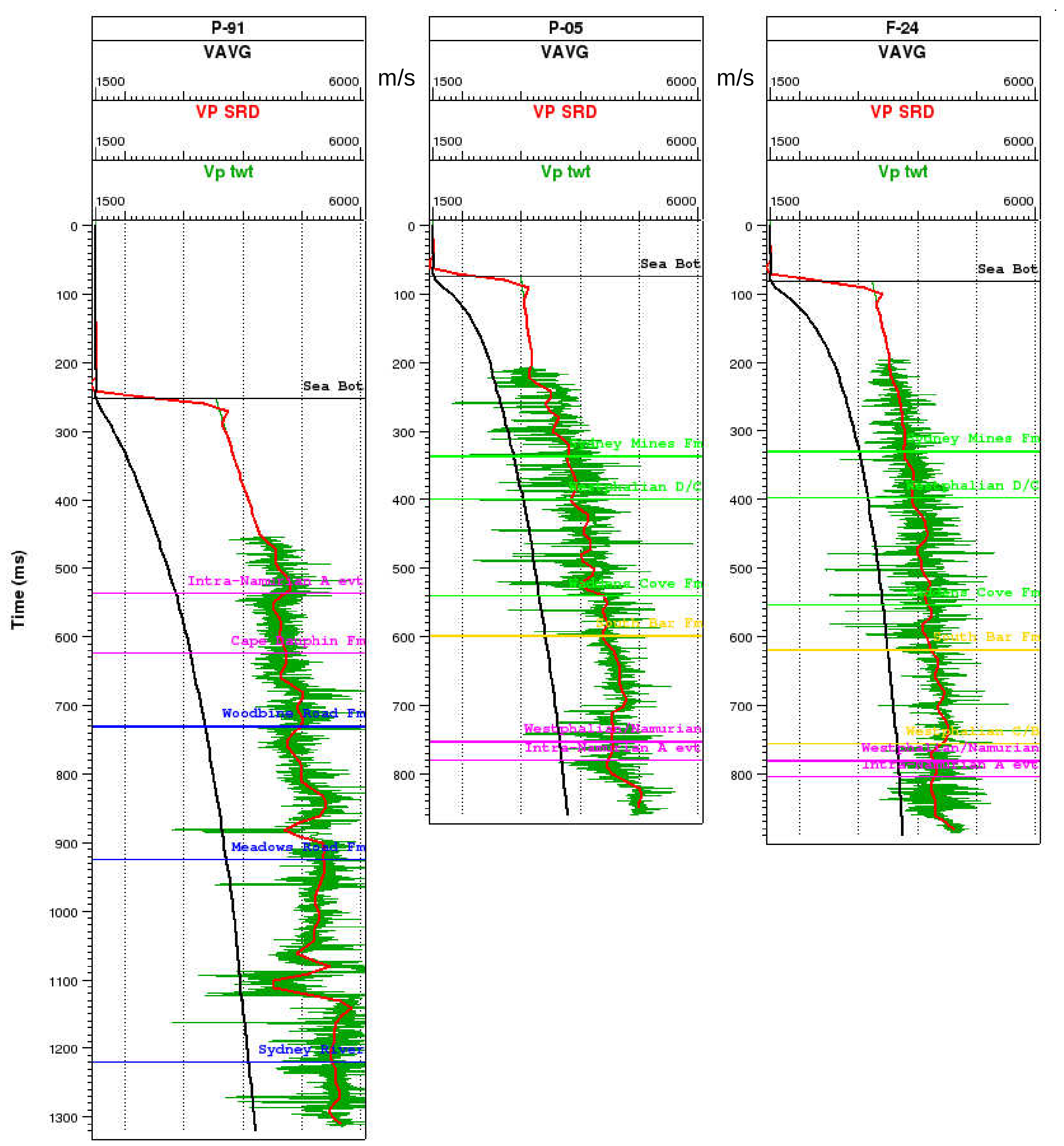


Figure 1: Original velocity logs in the three offshore wells (sonic drift < 10ms)
(green: instantaneous velocity – red: smoothed 15 Hz – black: average velocity)

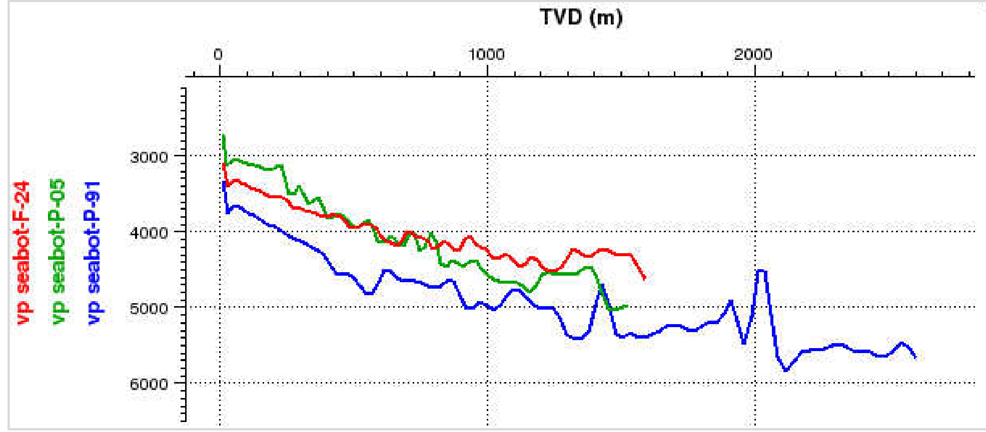


Figure 2: Referencing of the logs in True Vertical Depth from Sea Bed

P-91 shifted 700 m under

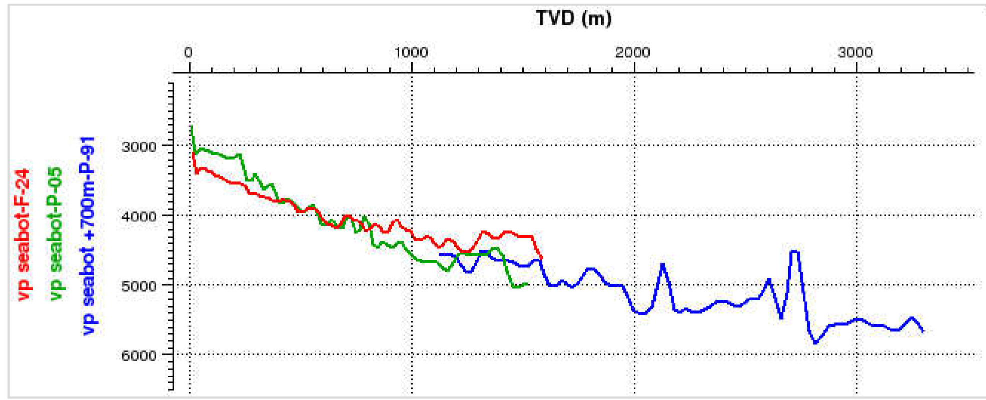
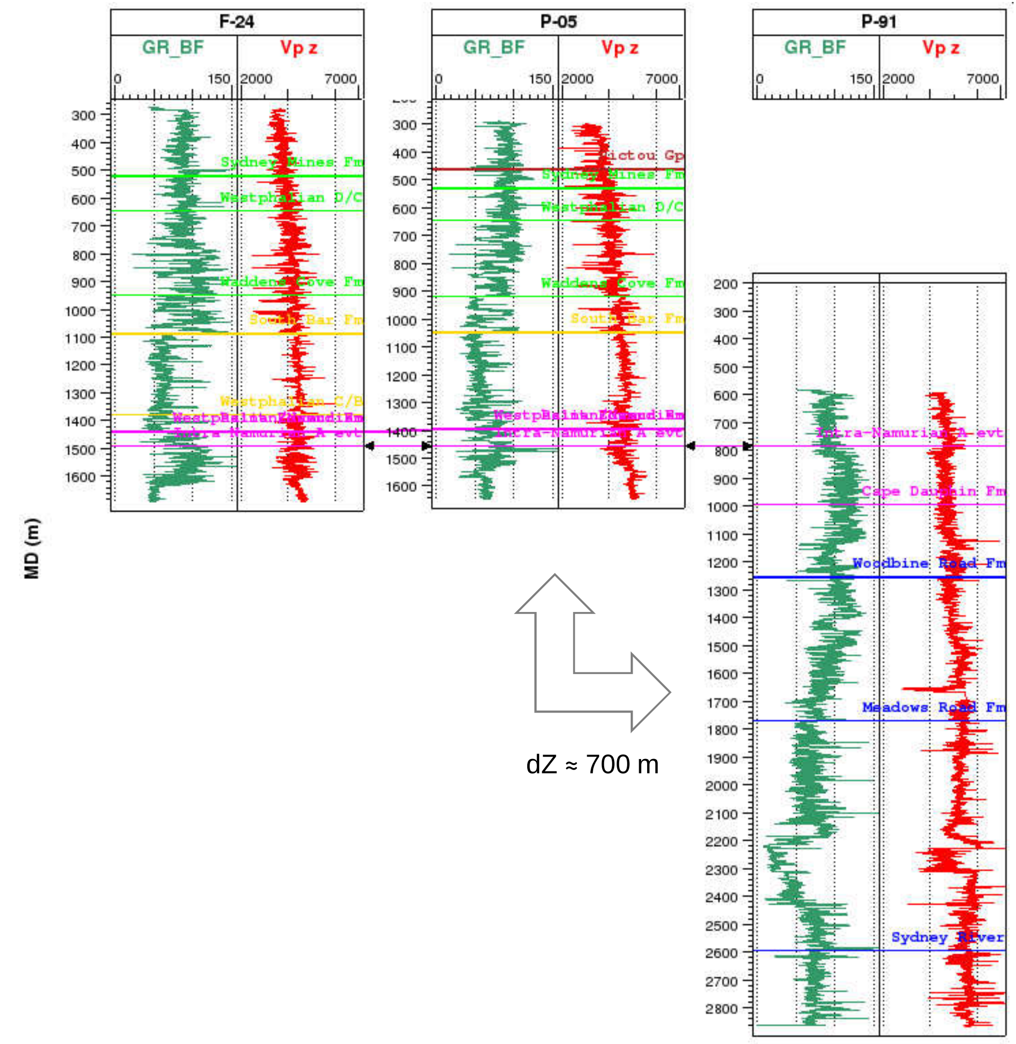


Figure 3: Referencing P-91's velocity log at equivalent burial state



Second Step: Analytic Regressions

(a) Binomial regression from the three wells (Figure 4);
(b) This regression cannot be used below 3 km (apex of the square function – Figure 5) → second binomial regression from P-91 for high depths (Z > 3 km SSB ≡ TWT > 1300 ms SSB – Figure 6);
(c) This second regression cannot be used below 6 km (apex of the square function – Figure 7) → assignation of 6000 m/s constant velocity from 6 km SSB ≡ 2230 ms SSB (in P-140: Vp in basement = 5800 m/s)

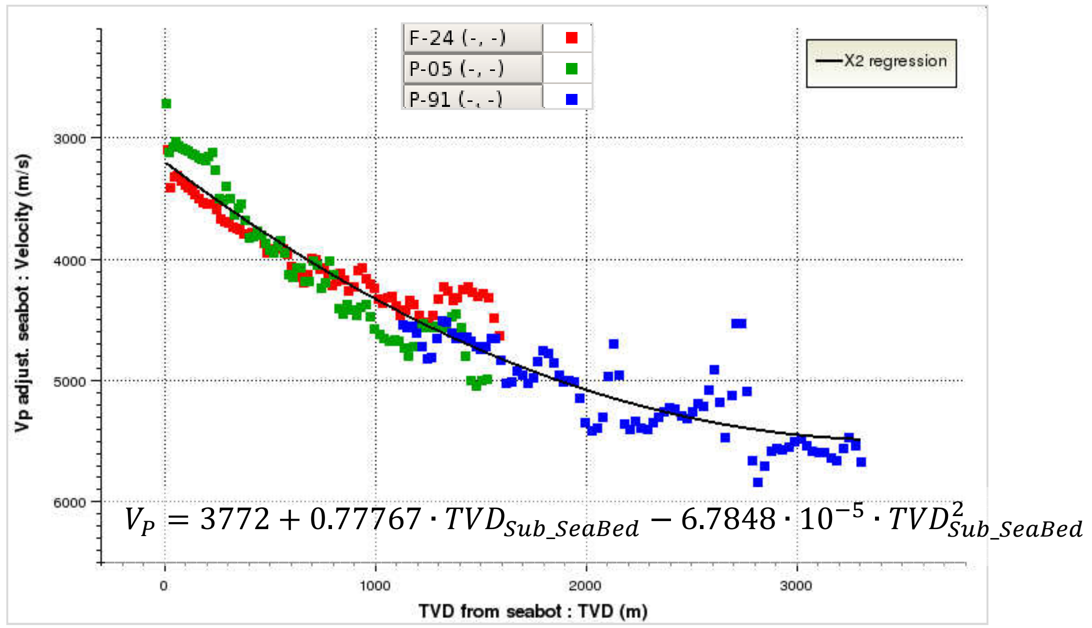


Figure 4: First binomial regression

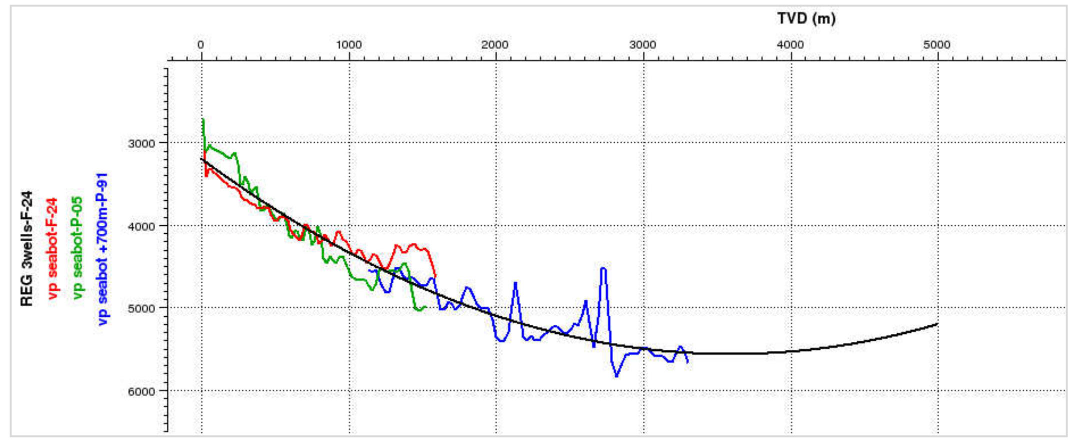


Figure 5: Unsuitability of the first regression for Z > 3 km

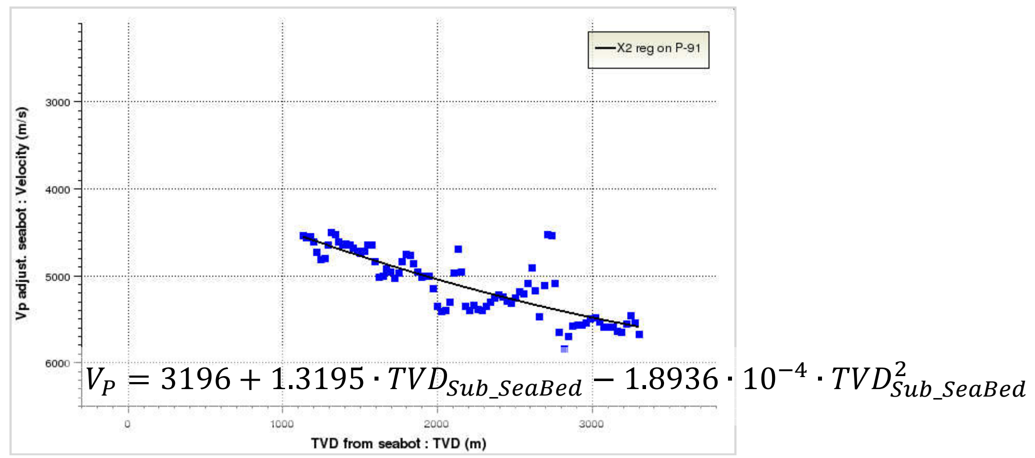


Figure 6: Second binomial regression for Z > 3 km

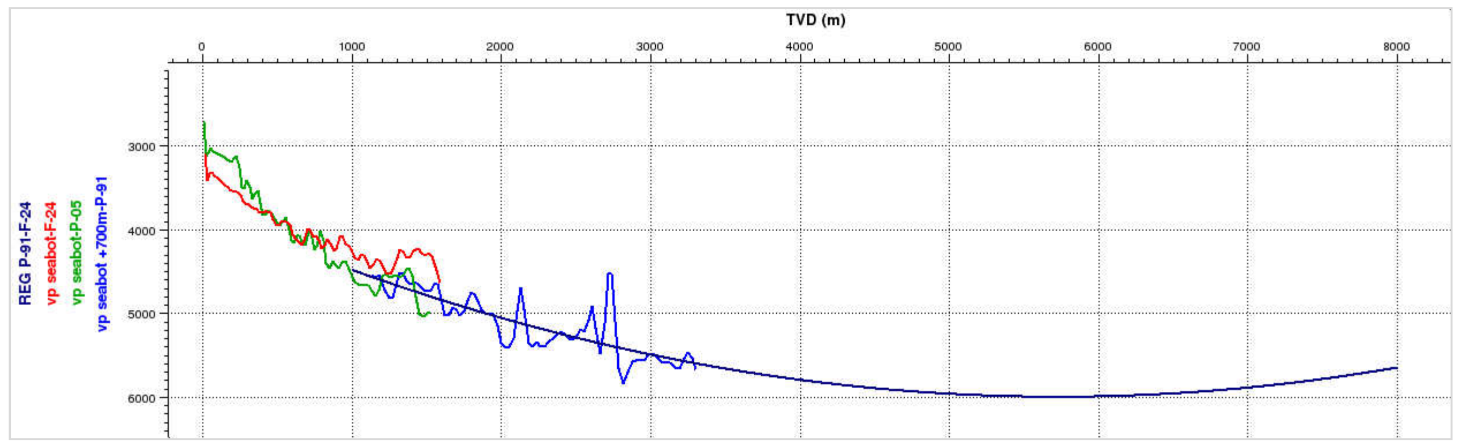
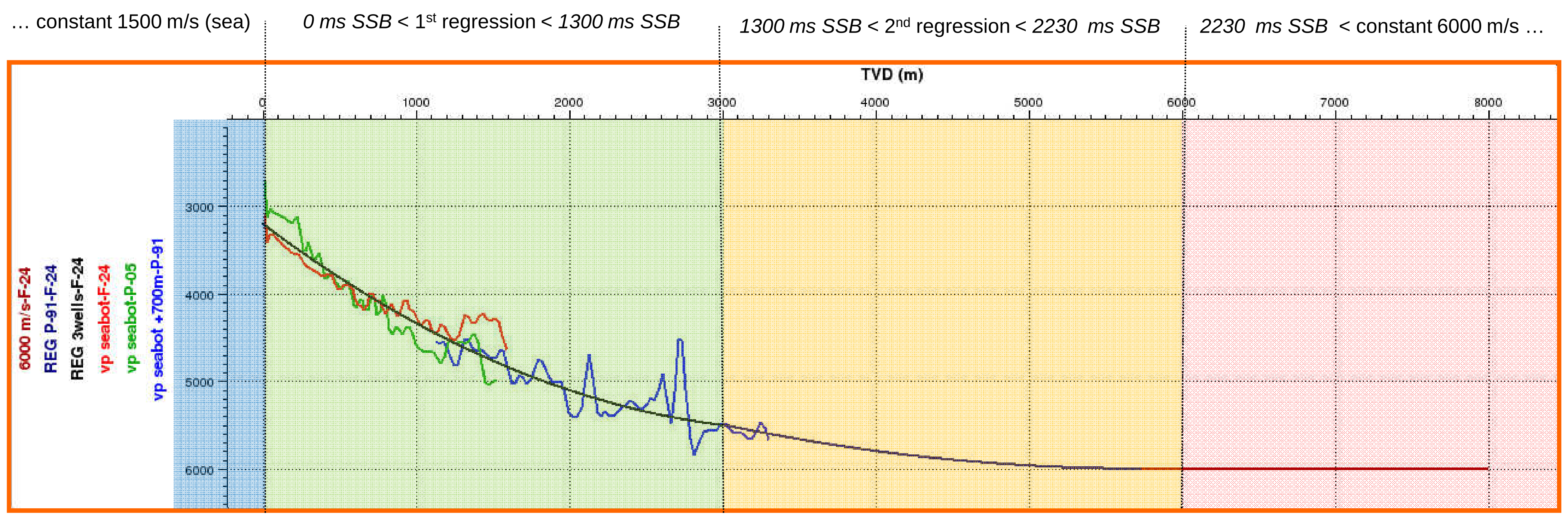


Figure 7: Unsuitability of the second regression for Z > 6 km



	Layer Name	Use	Top Boundary	Domain	Formation	Conformance
1	Sea cst	✓	cst0sec	Time	Water	None
2	L1	✓	SeaFloor_Atlantic	Time	Layer 1	Water Bottom
3	L2	✓	SFA_+1300	Time	Layer 2	Water Bottom
4	L3 cst	✓	SFA_+2230	Time	V6000ms	None

Figure 1: Final velocity model in four TWT layers

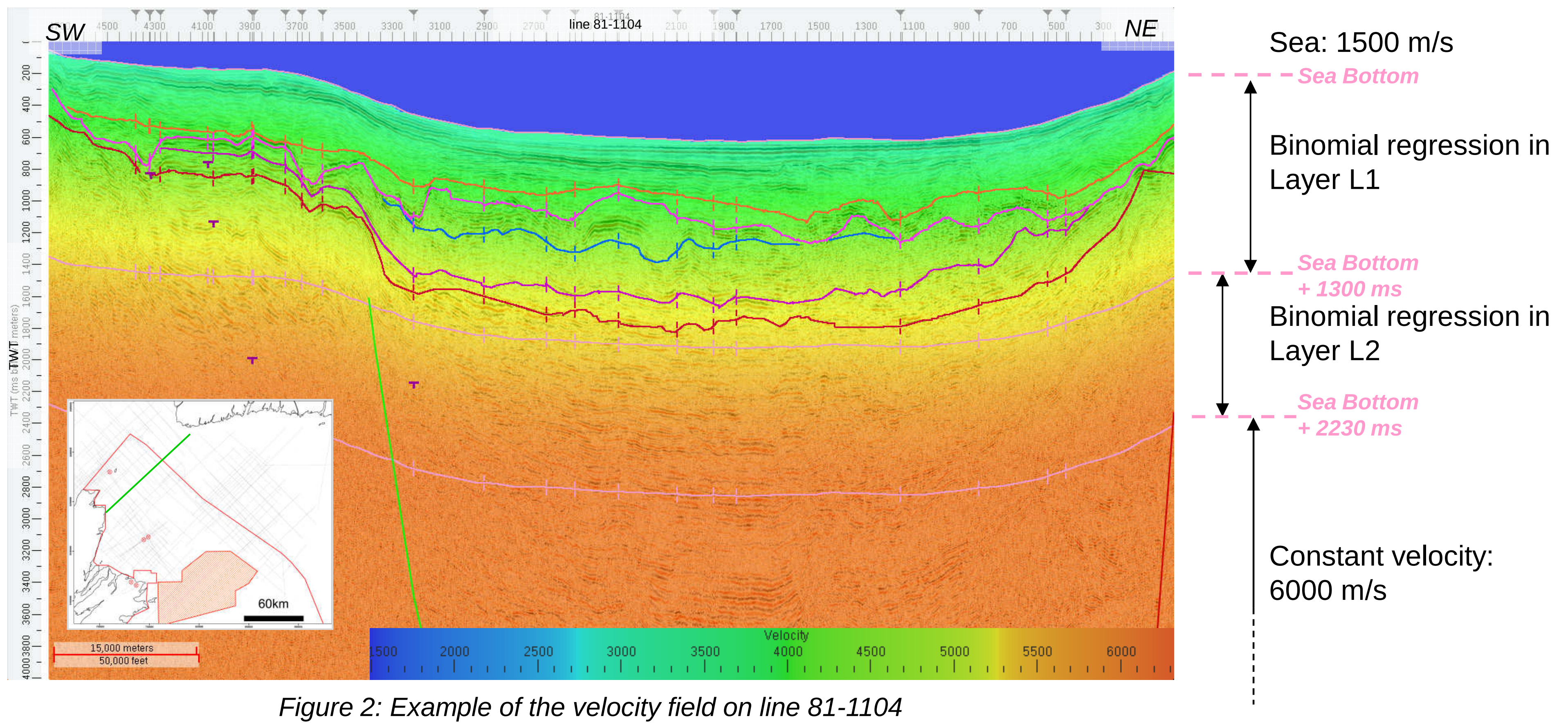


Figure 2: Example of the velocity field on line 81-1104

Third Step: Inputting into *DecisionSpace Desktop*'s Velocity Modeling

(a) Creation of two artificial horizons (*Sea_Floor_+1300ms* and *Sea_Floor_+2230ms*)

(b) Definition of the four layers in TWT (Figure 1);

(c) Assignment of the model to the lines for direct conversion (Figure 2).

QC'ing the Velocity Model

Model QC can only be made through the picks present in the three wells and whose horizons are interpreted (Top South Bar, Westphalian/Namurian Unconformity and Top Windsor).

This error is displayed in Figure 3: for the North Sydney wells, it remains very low (< 3%) which is acceptable, whereas – from construction – the analytic model has excessively low velocities in the Cabot High (~ 10% too low). Therefore, a local correction was made around the Cabot High to adjust the depth conversion to the well values.

Examples of the time-to-depth conversion are illustrated in Figures 4 and 5.

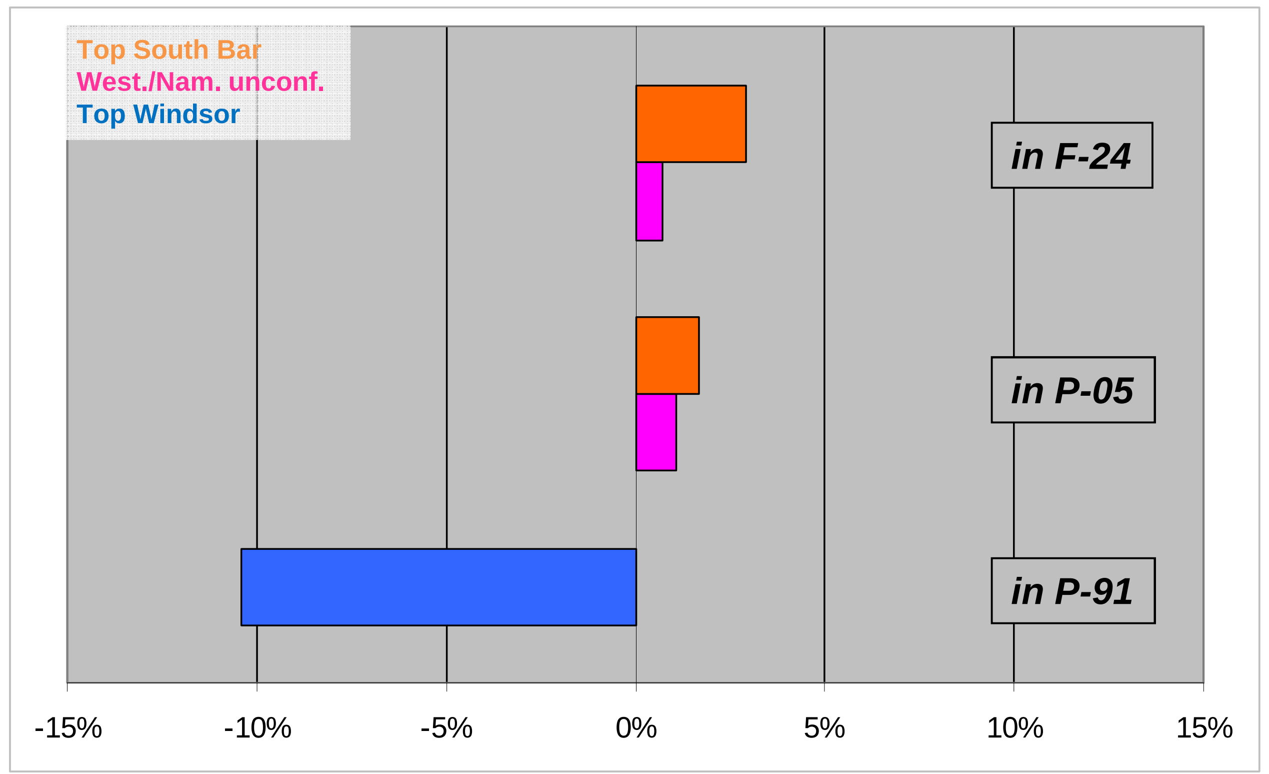


Figure 3: Depth errors at the wells

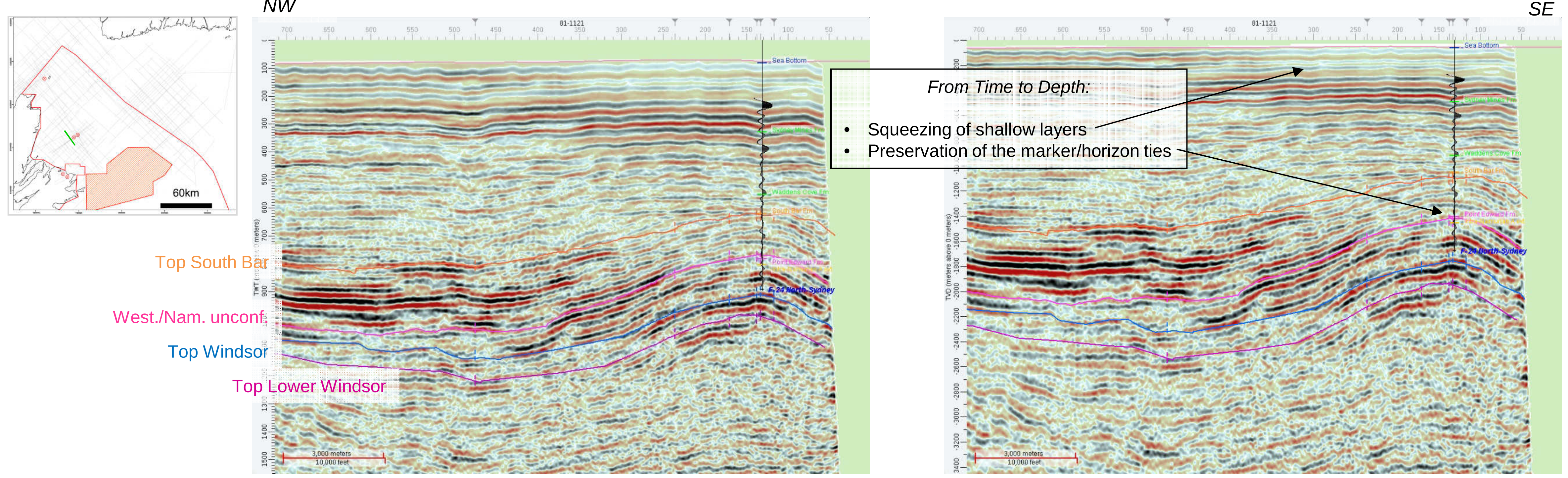


Figure 4: Part of line 81-1121 crossing F-24: in TWT (left) then Zss (right)

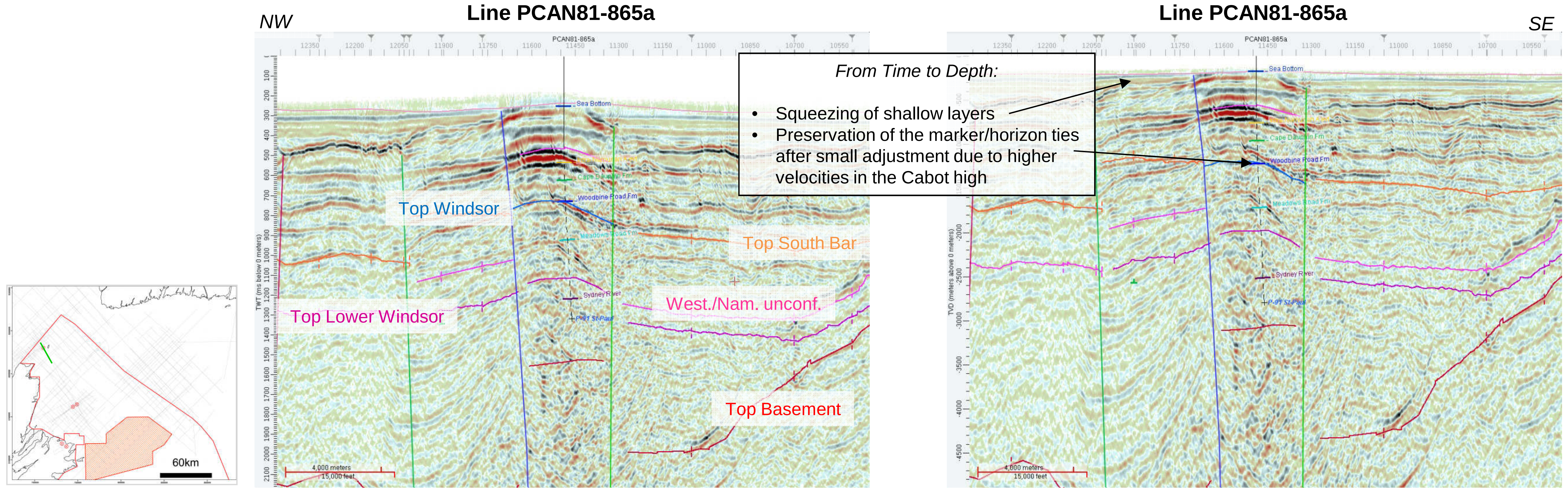
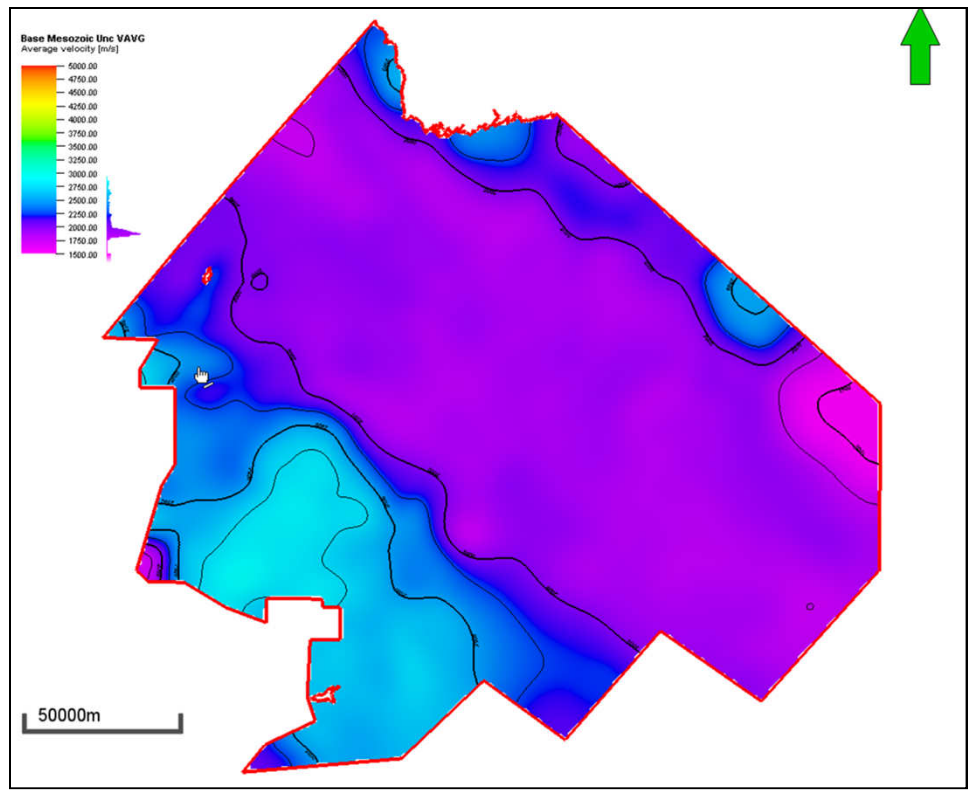
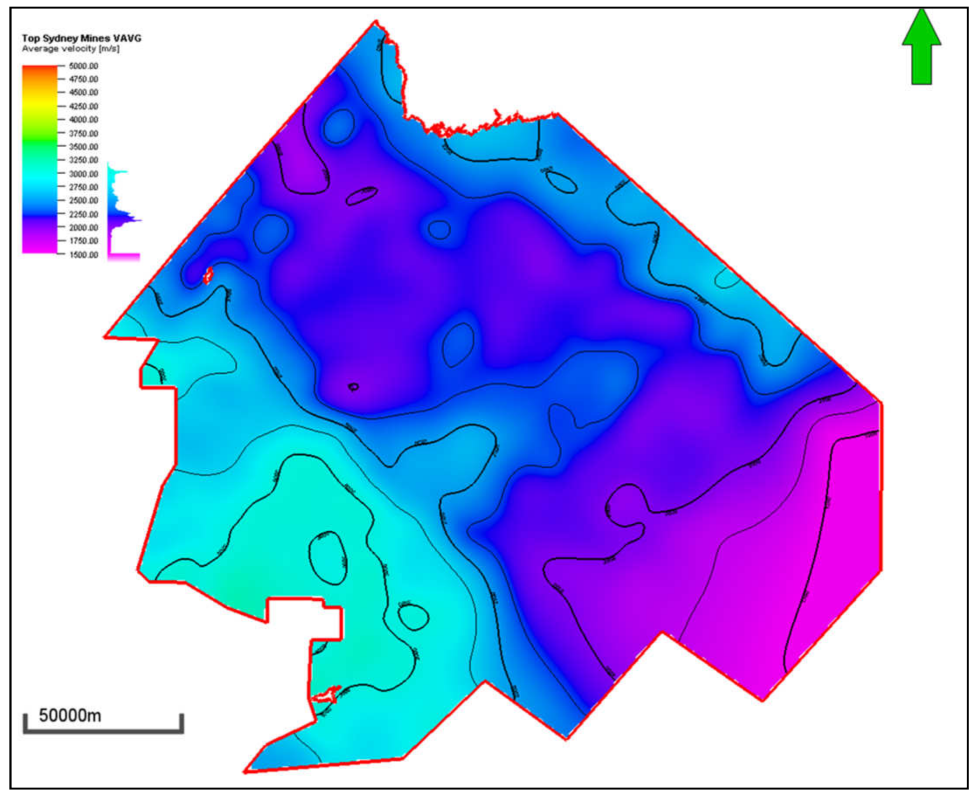


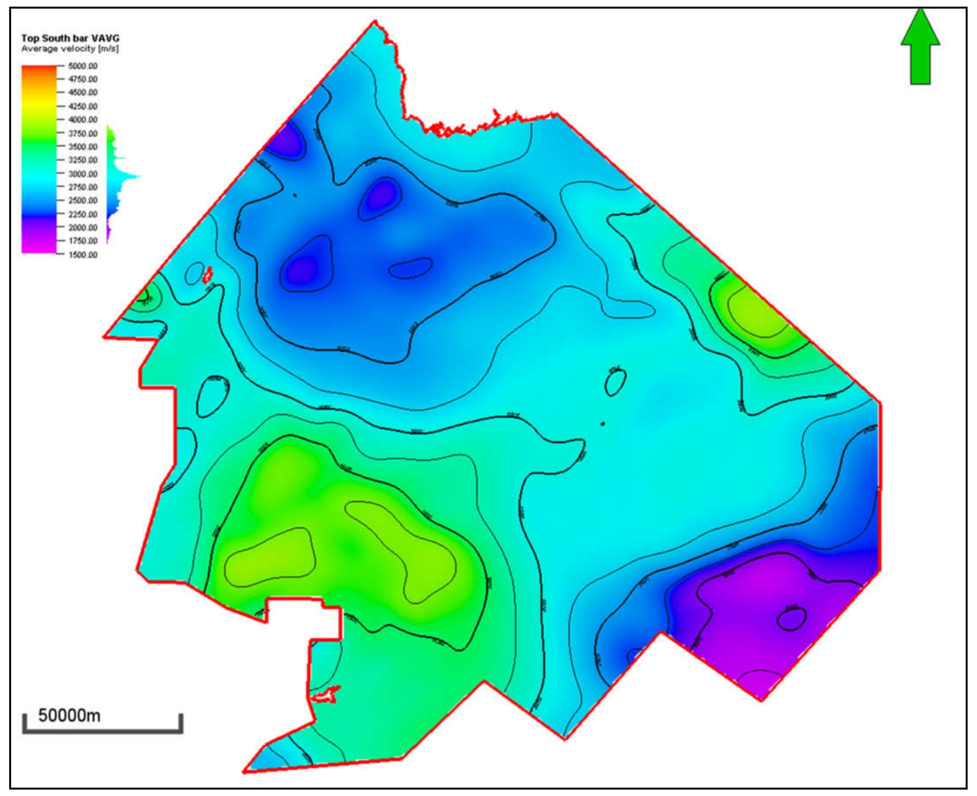
Figure 5: Part of line PCAN81-865a crossing P-91: in TWT (left) then Zss after adjustment (right)



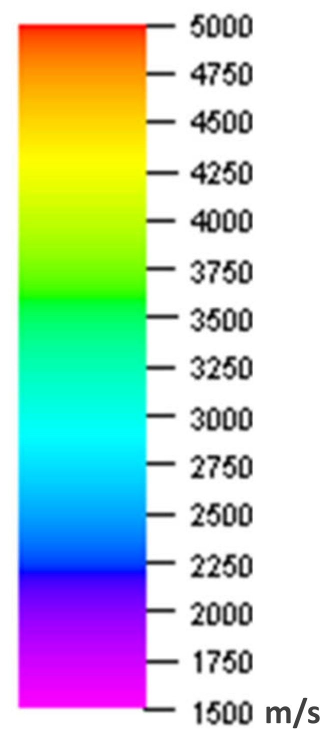
Base Mesozoic Unc.



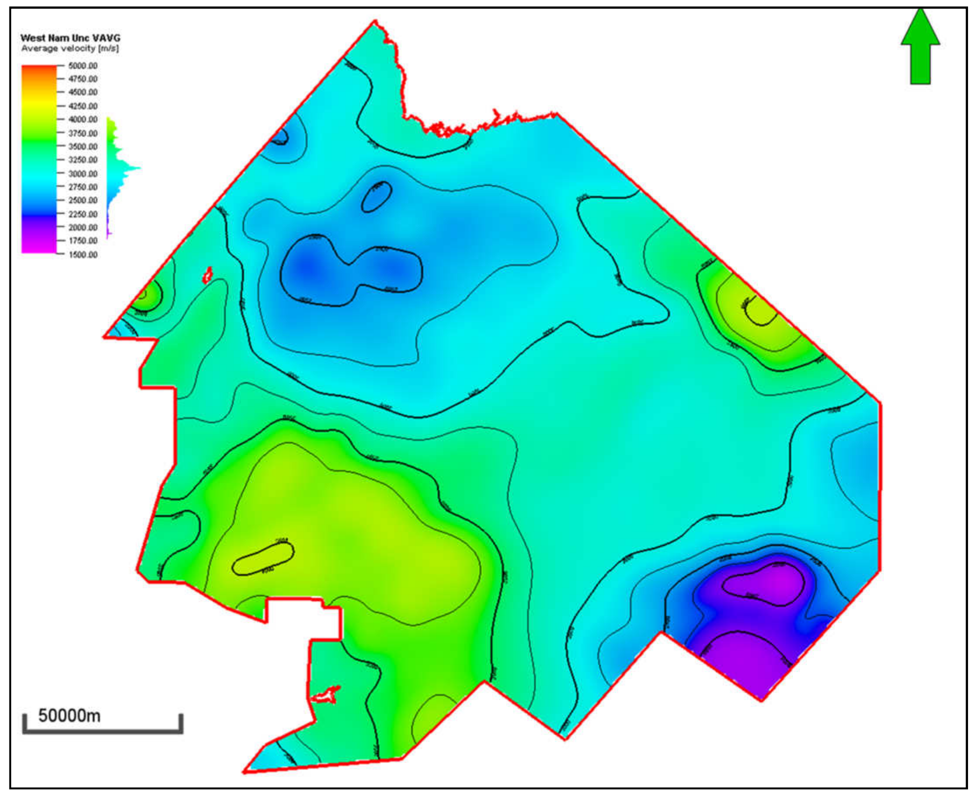
Top Sydney Mines



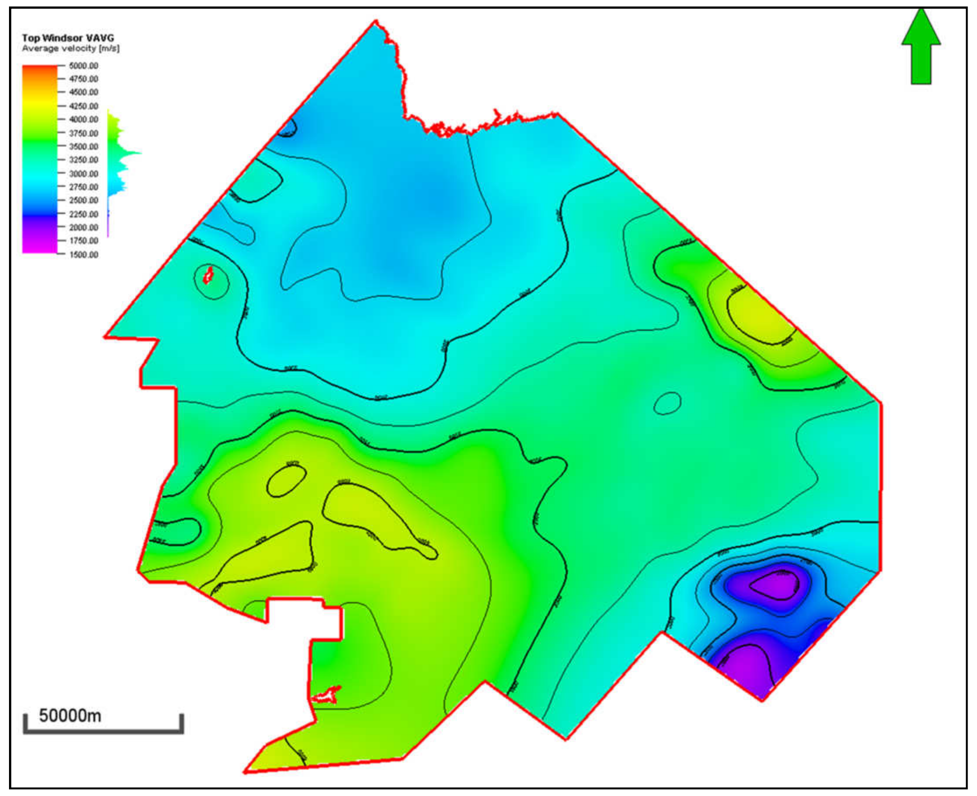
Top South Bar



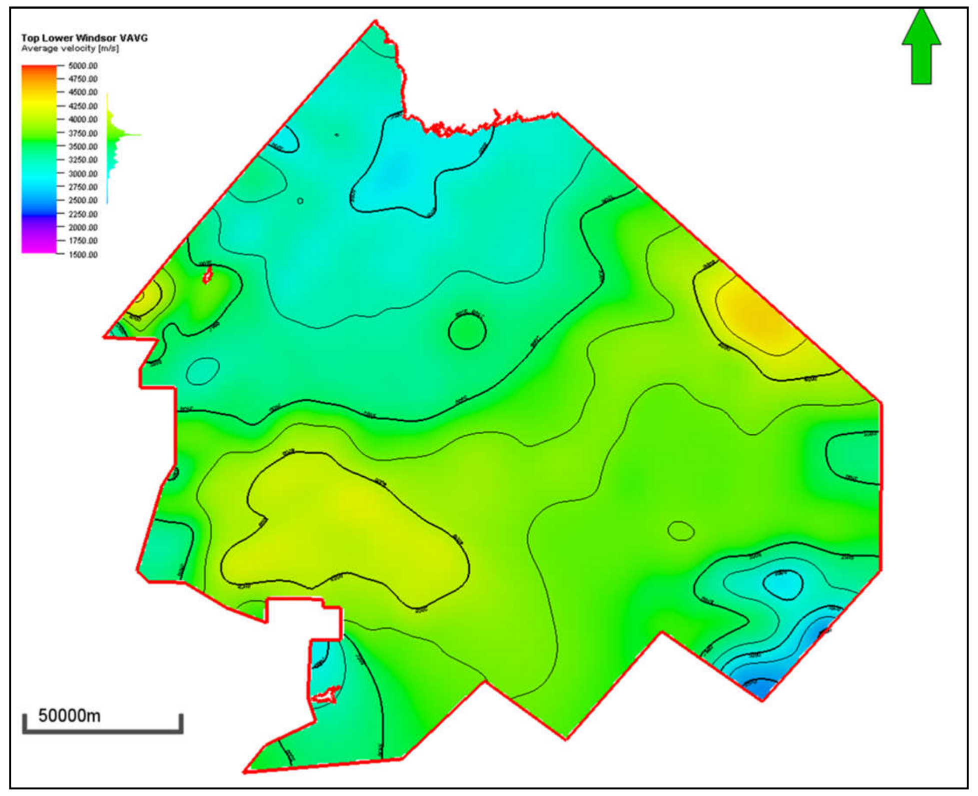
contour: every 250 m/s
***bold** contour: every 500 m/s*



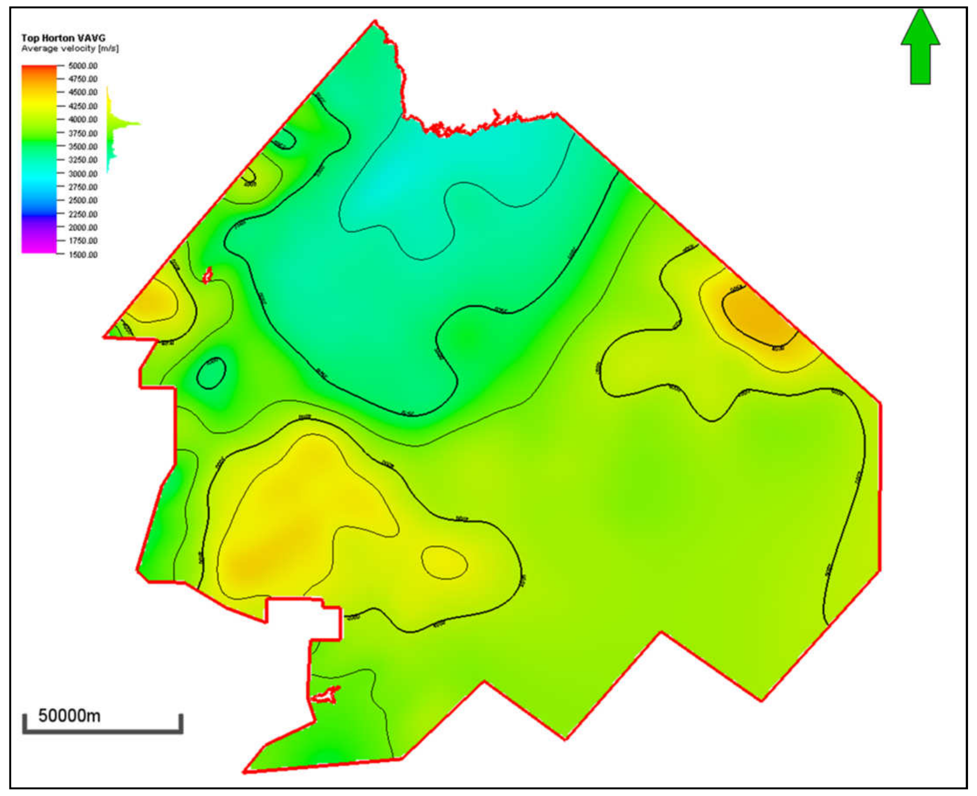
Westphalian/Namurian Unc.



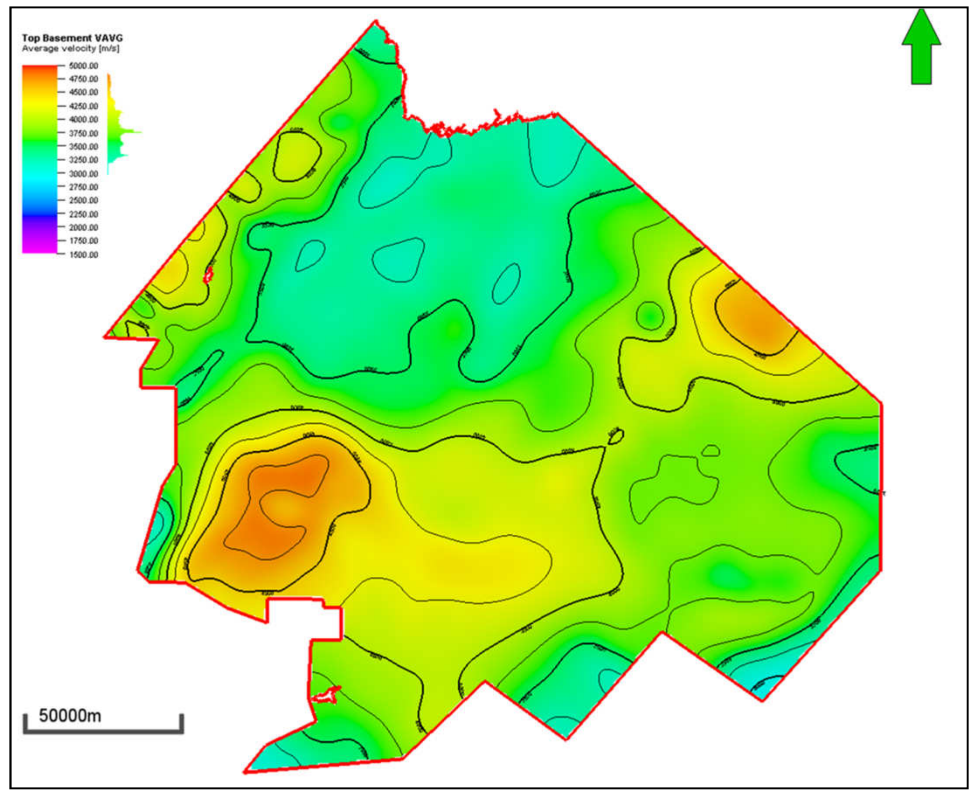
Top Windsor



Top Lower Windsor



Top Horton



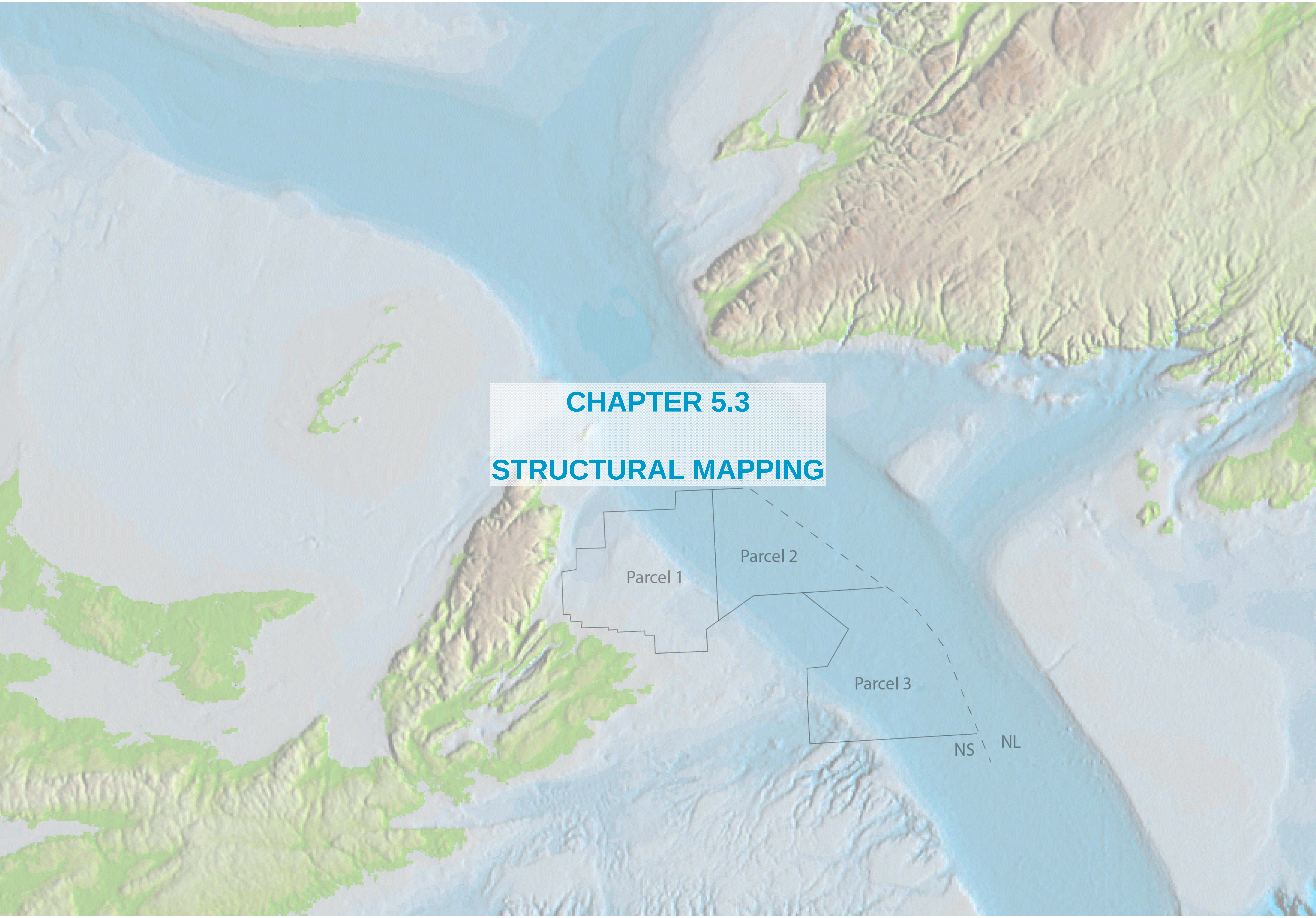
Top Basement

Average Velocity maps

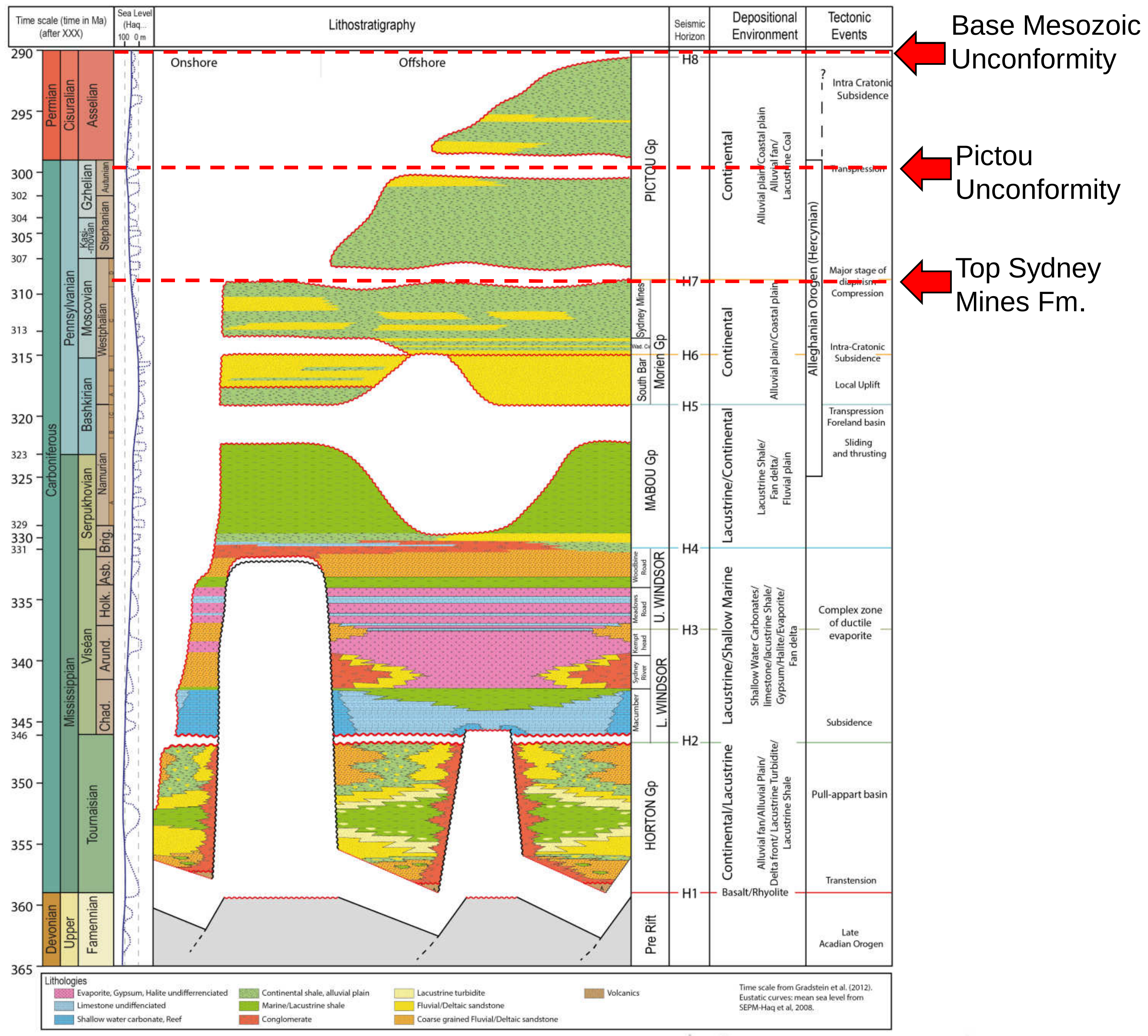
An average velocity map from the sea level datum was computed for each of the interpreted horizons. They show a regular increase of their values with the compaction depth.

CHAPTER 5.3

STRUCTURAL MAPPING



Tectono-Stratigraphic Chart



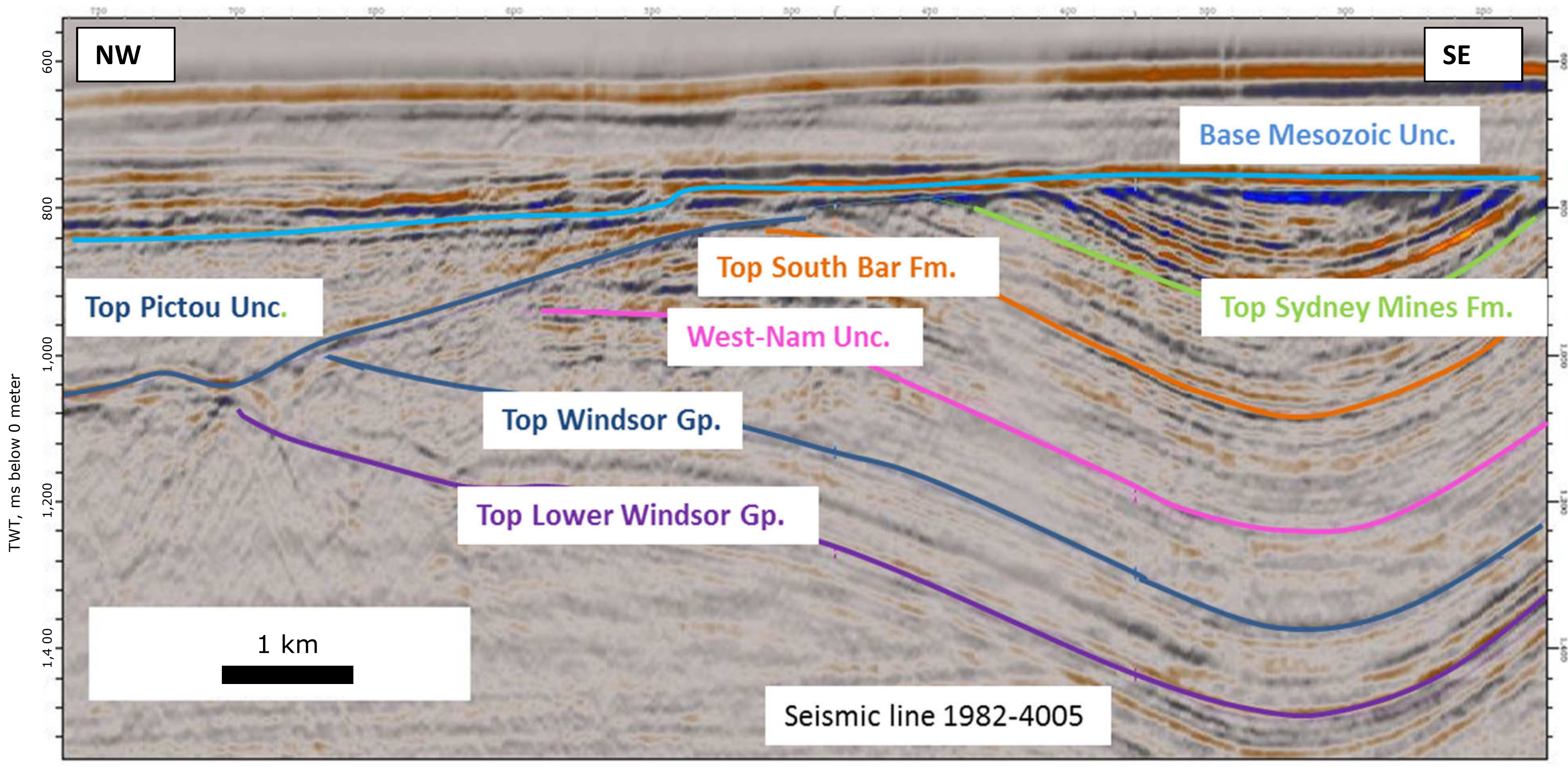


Figure 1: Seismic line 1982-4005 (location on Figures 3 and 5) showing the Base Mesozoic Unconformity and Pictou Unconformity.

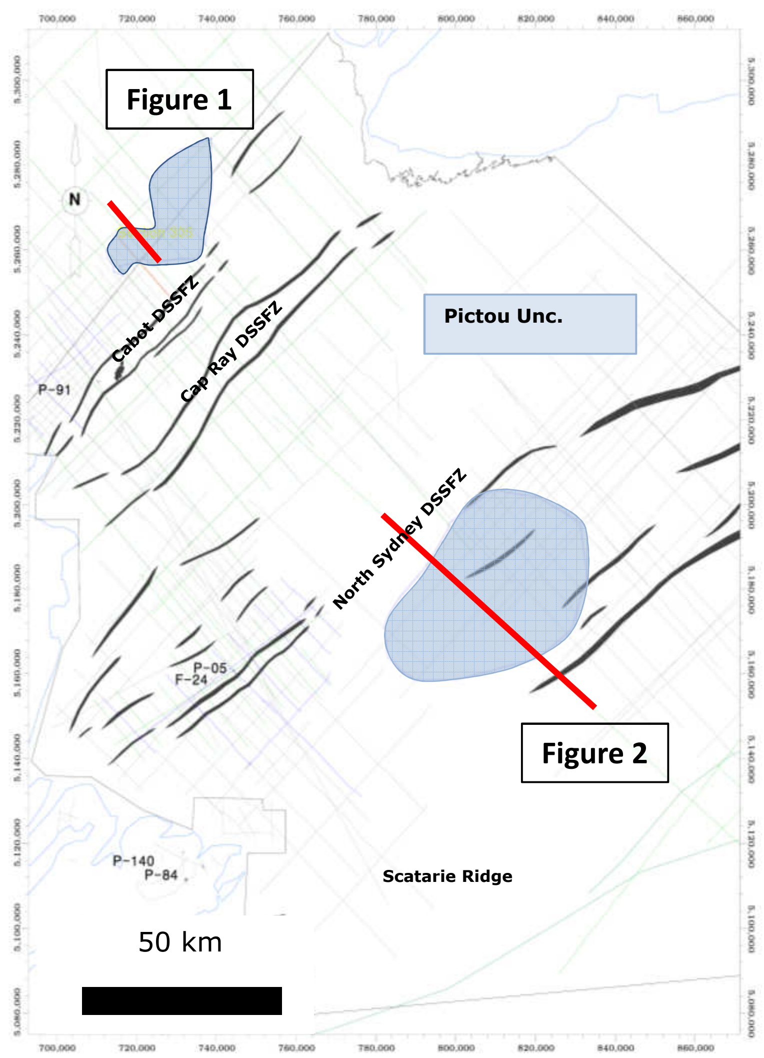


Figure 5: Map showing the presence of the Pictou Unconformity (areas in blue) west of the Cabot Dextral Strike Slip Fault Zone (DSSFZ) and East of the North Sydney Dextral Strike Slip Fault Zone (DSSFZ). The red lines correspond to the seismic lines displayed in Figures 1 and 2.

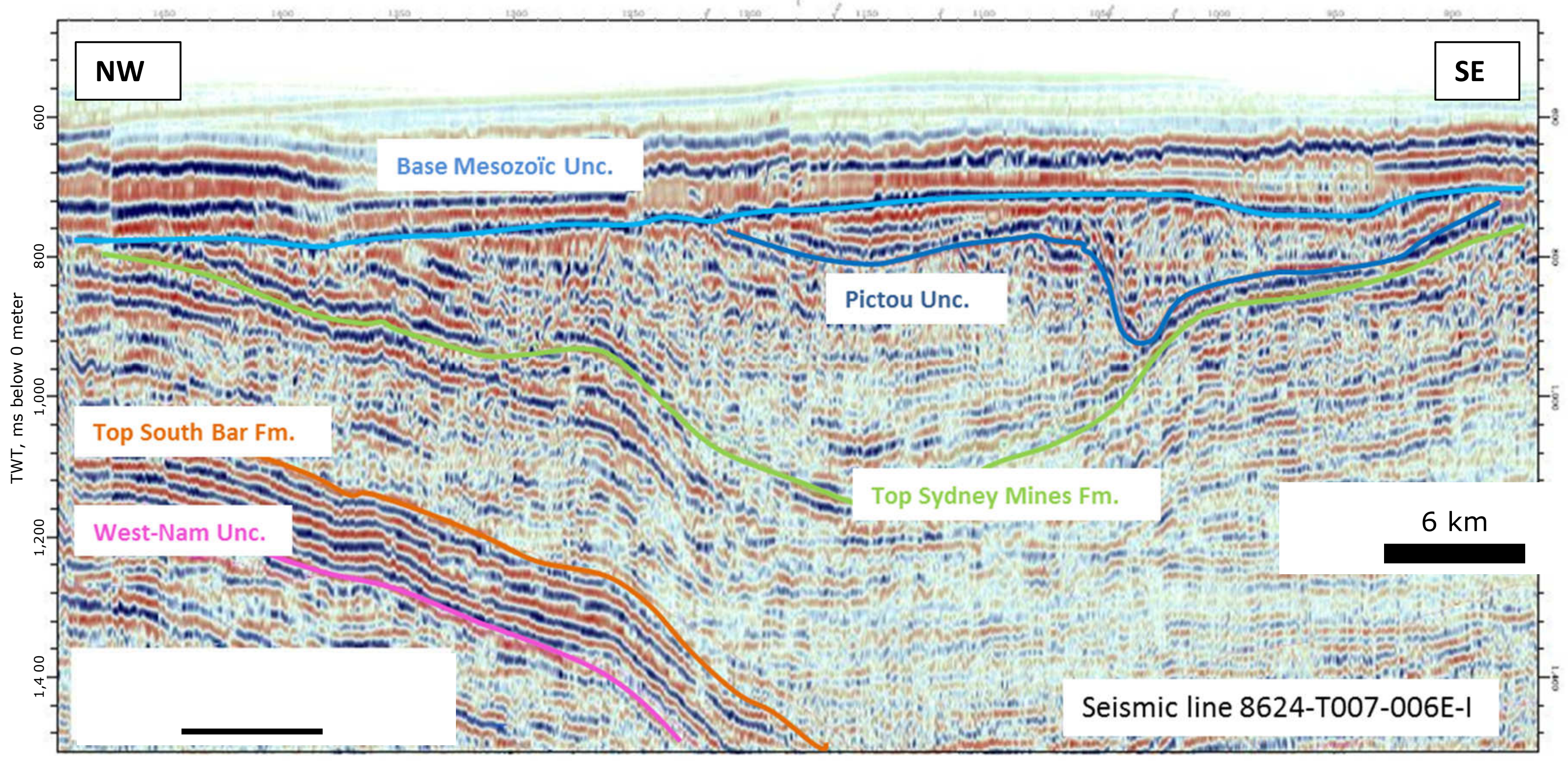


Figure 2: Seismic line 8624-T007-006E-I (location on Figures 3 and 5) showing the Base Mesozoic Unconformity and a channel interpreted as the Pictou Unconformity. These unconformities are cutting older horizons locally down to the basement.

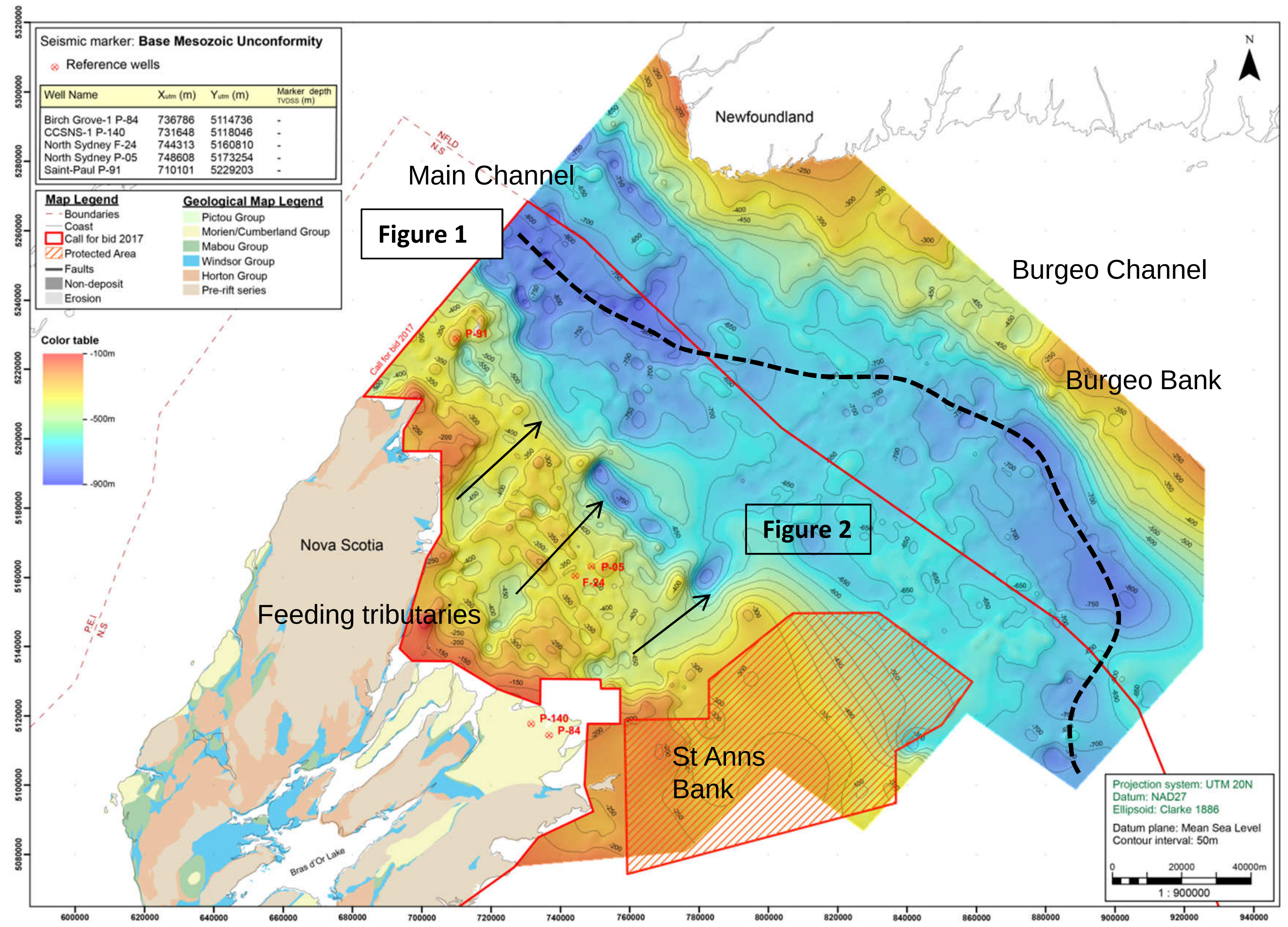


Figure 3: Depth (TVDSS) Map of the Base Mesozoic Unconformity showing that the erosion is associated with the ancestral Saint Laurence River, its main meander (dark blue) and lateral tributaries (black arrows).

Horizon Definitions:

The shallowest interpreted horizons in Sydney Basin are the Base Mesozoic and Pictou Unconformities. The horizon named "**Base Mesozoic Unconformity**" is an erosional surface corresponding to attrition by the ancestral Saint Lawrence River that has been present since the Mesozoic. It is the shallowest unconformity present in Sydney Basin. The lateral extrapolation of this unconformity is simple to track because it is an erosional surface that cuts across all previous formations, as shown on Figures 1 and 2. The Base Mesozoic Unconformity map (Figure 3) shows the influence of the Saint Lawrence River and its tributaries draining Nova Scotia north of the St. Anns Bank, and Newfoundland on either sides of the Burgeo Bank.

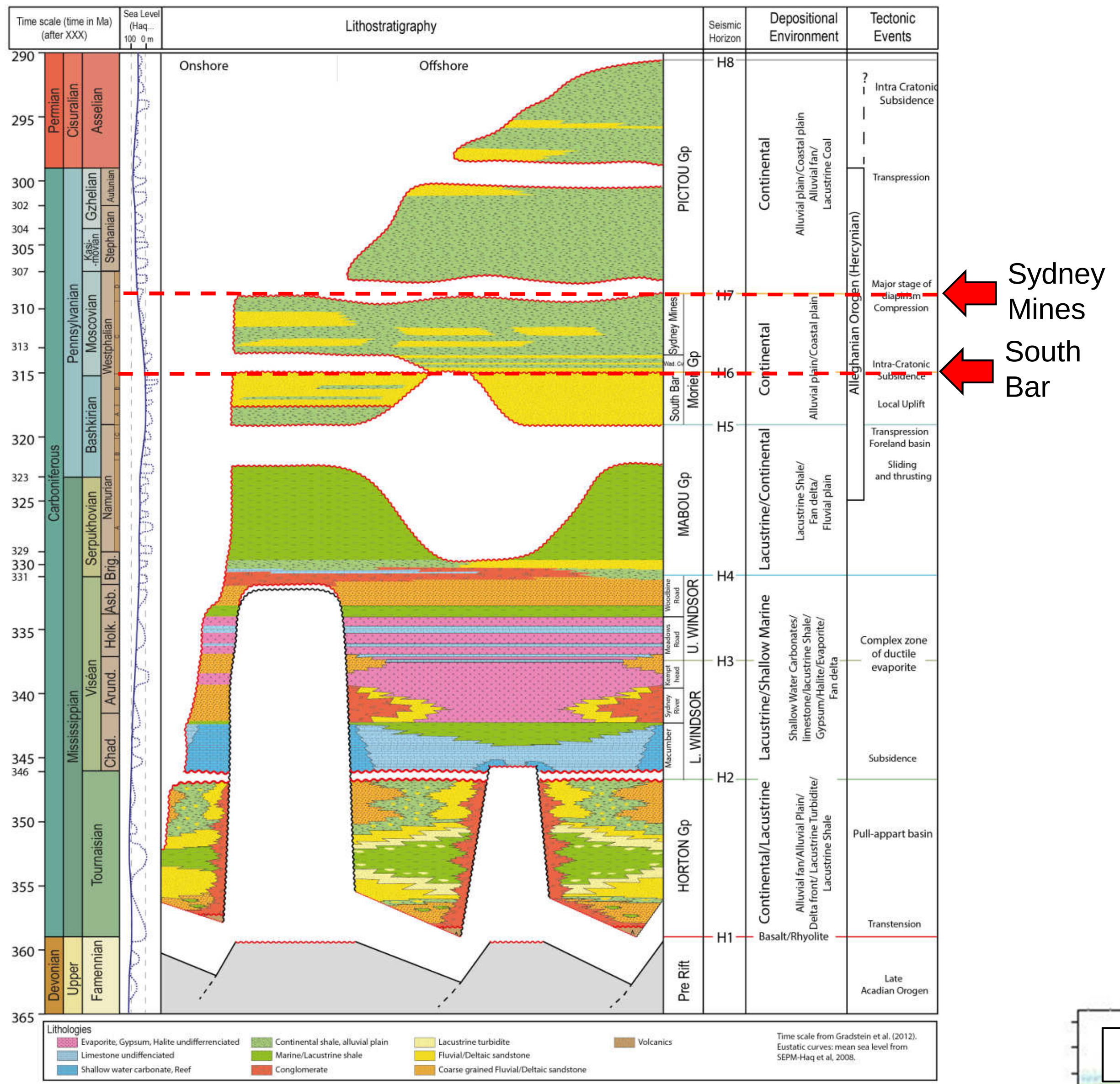
The horizon named "**Pictou Unconformity**" is an intra Pictou erosional surface that has been correlated with the base Permian. Its age has been estimated at 300 million years. It can only be observed in two locations (Figure 5) along the Cabot fault zone constituting the NW limit of the Sydney Basin (see seismic lines 4005) where it cuts the top of the Sydney Mines Formation, and in the center of the Sydney Basin (see seismic lines 8624-T007-006E-I). In the rest of the Sydney Basin, the Pictou Unconformity has been truncated by the Base Mesozoic Unconformity.

Seismic Picking and Uncertainty

Though penetrated by the three offshore wells, none of these unconformities have been properly calibrated. The well to seismic tie is not constrained at Saint Paul P-91 as the stratigraphic records starts 610 MD in the Mabou Formation. Top Sydney Mines is the shallowest horizon tied with the offshore North Sydney wells P9 and F24. Despite the lack of well ties, the lateral extrapolation of the Base Mesozoic and Pictou Unconformities are relatively easy to track when associated with obvious truncations.

SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

Tectono-Stratigraphical Chart



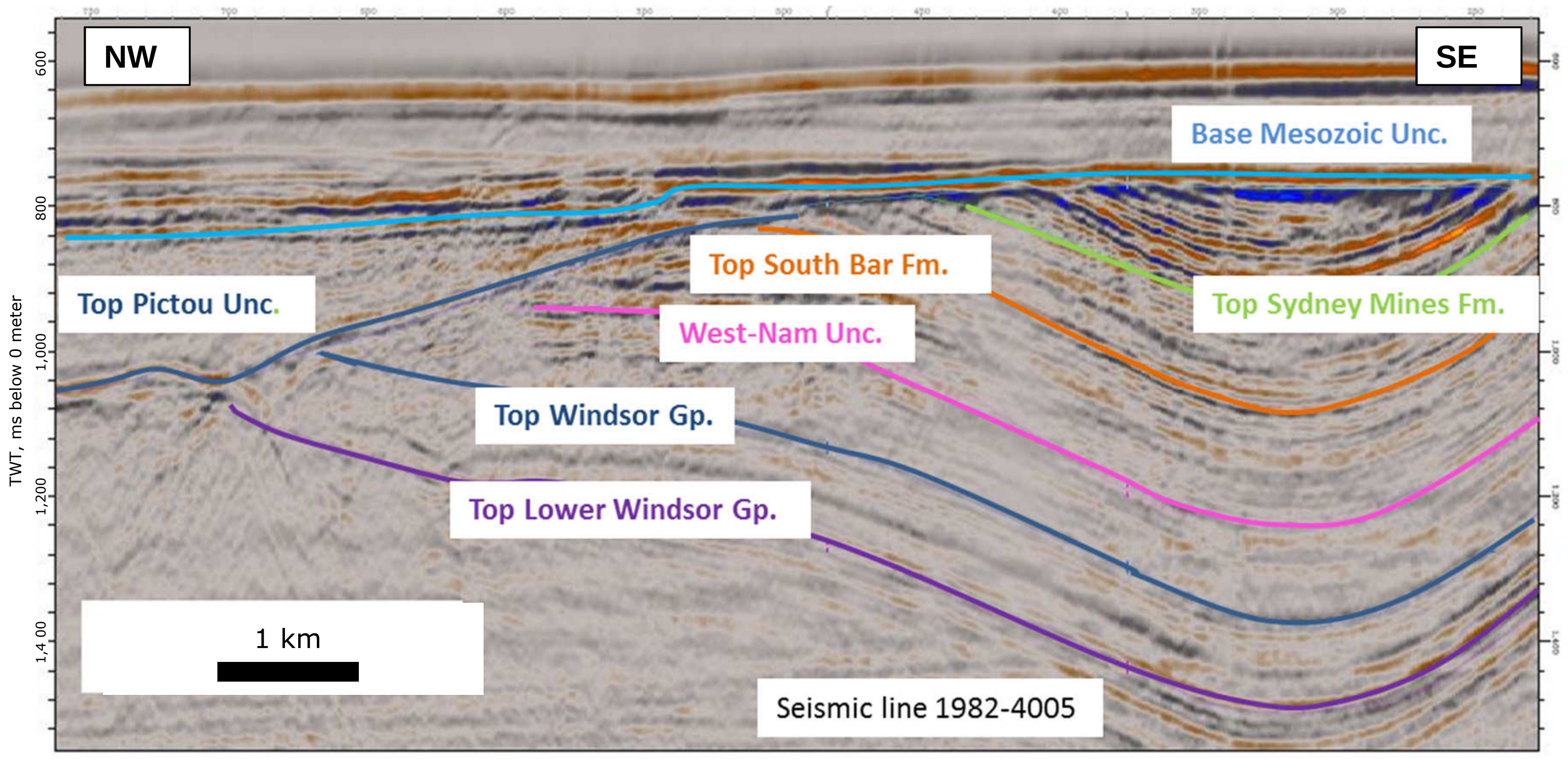


Figure 1: Seismic line 1982-4005 reflectivity data showing Top Sydney Mines Fm. truncated by the Base Mesozoic and Pictou Unconformities. For seismic line locations, see Figure 3.

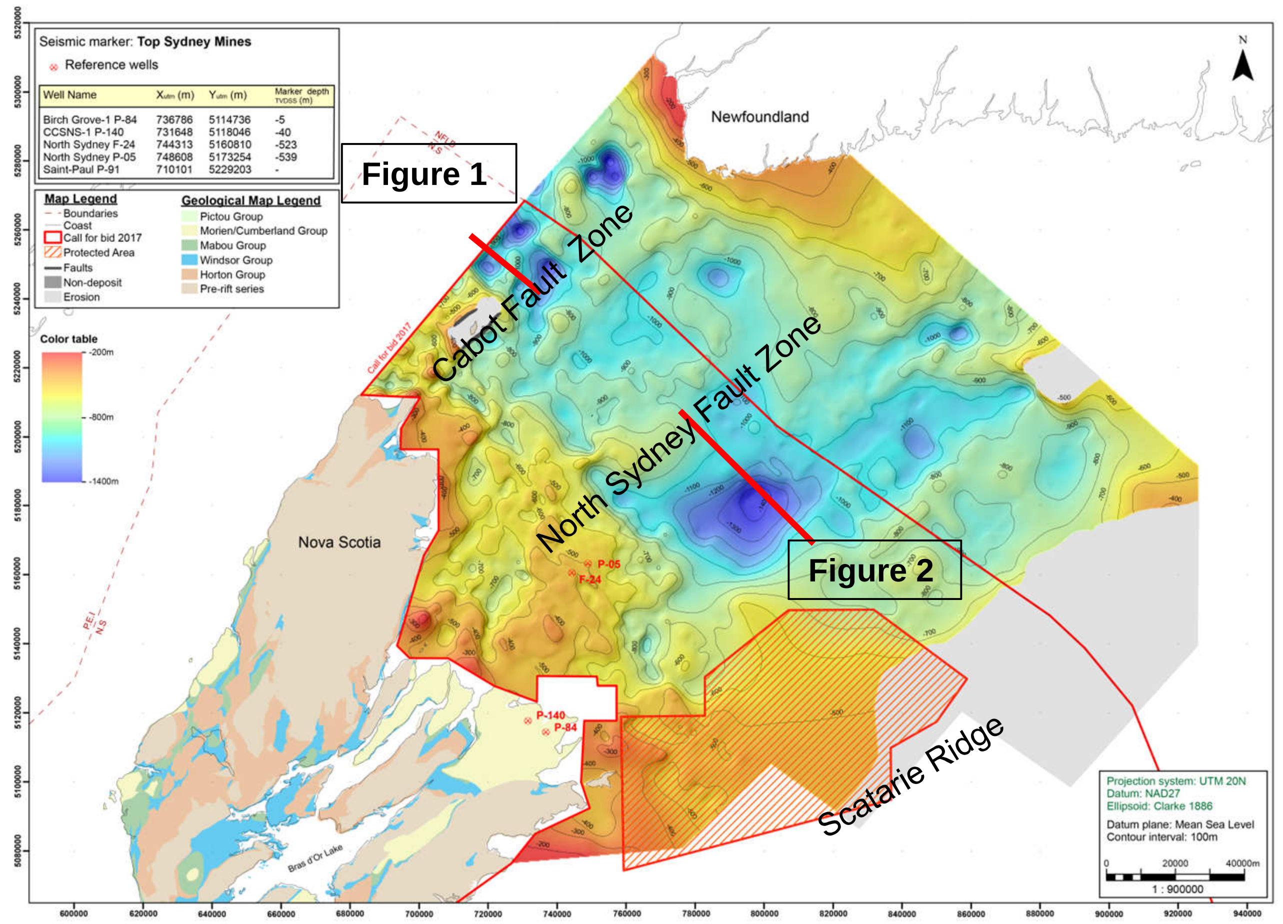


Figure 3: Depth (TVDSS) Map of Top Sydney Mines Formation showing erosional areas (grey) beneath Base Mesozoïc and Pictou Unconformities.

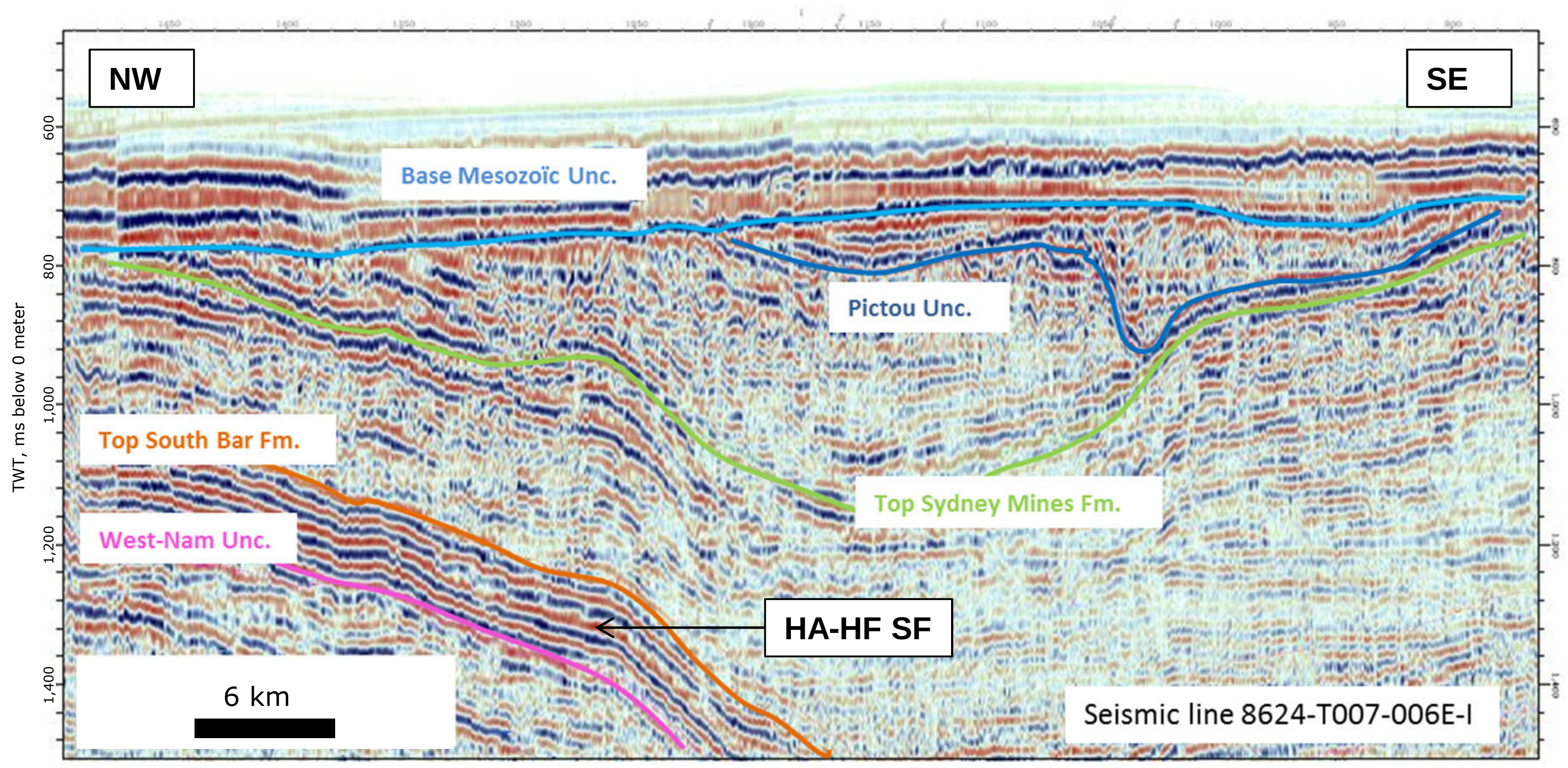


Figure 2: Seismic line 8624-T007-006E-I reflectivity data showing Top Sydney Mines Fm. truncated by the Base Mesozoic and Pictou Unconformities. This figure shows a seismic facies HA-HF locally characteristic of the Sydney Mines and South Bar Formations associated with the presence of coal seams. For seismic line locations, see Figure 3.

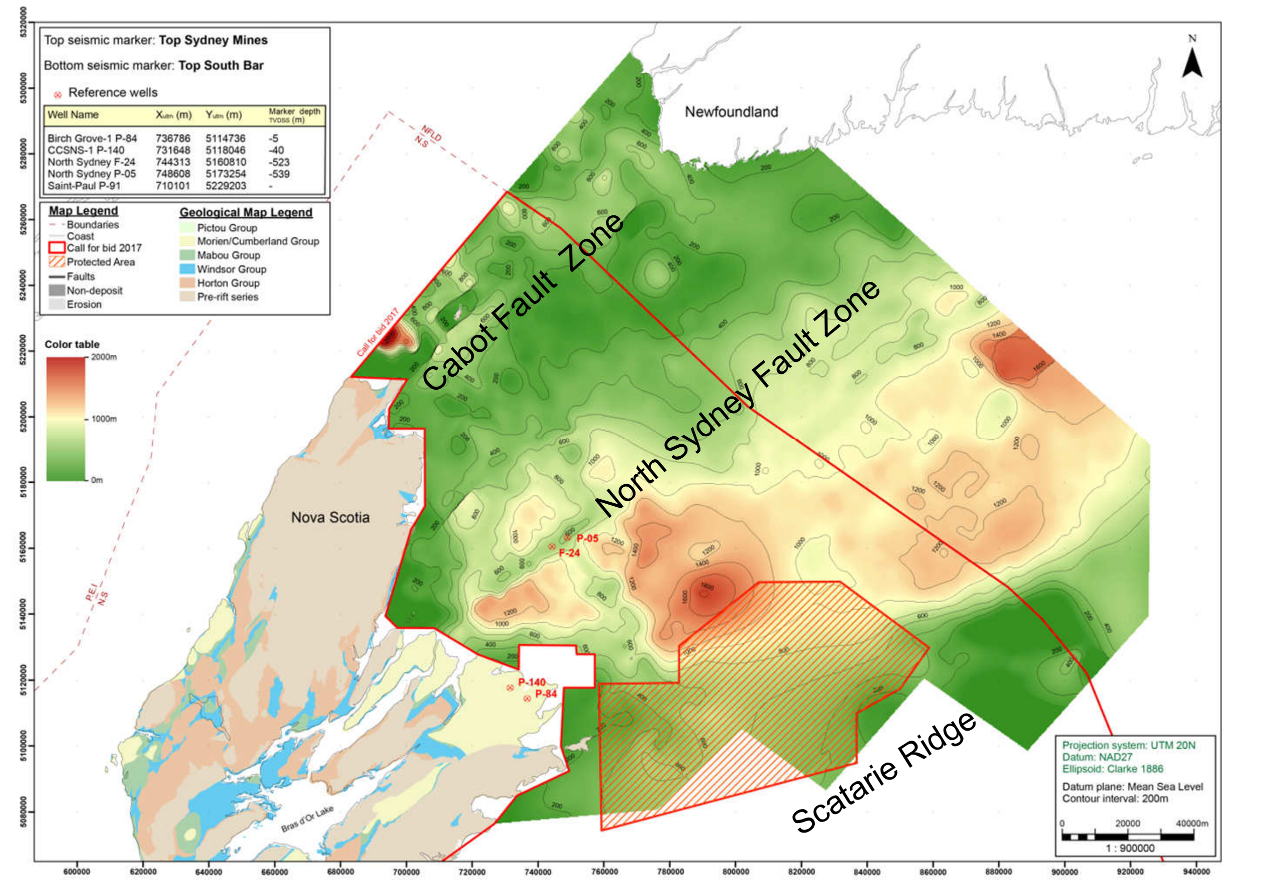


Figure 3: Thickness map between Top Sydney Mines Formation and Top South Bar showing erosional areas (grey) beneath Base Mesozoïc and Pictou Unconformities and that the depocenter is located between the North Sydney Fault Zone and Scatarie Ridge.

Horizons and Structural Description

The horizon named "**Top Sydney Mines Formation**" is a surface tied through offshore wells North Sydney P05 and F24 **(PL. 5.2.1.3; 5.2.1.4**). The age of this surface has been estimated at 309 million years. The Sydney Mines Formation is affected by broad folding; the anticlines are truncated by the Pictou Unconformity and the Base Mesozoic Unconformity as shown on Figure 2. Sydney Mines Formation is eroded over the Scatarie Ridge. The high amplitude – high frequency seismic facies (HA-HF SF) is locally characteristic of the Sydney Mines Formation and interpreted as being due to the presence of coal seams within strata deposited in a strictly continental environment.

Well to Seismic Tie

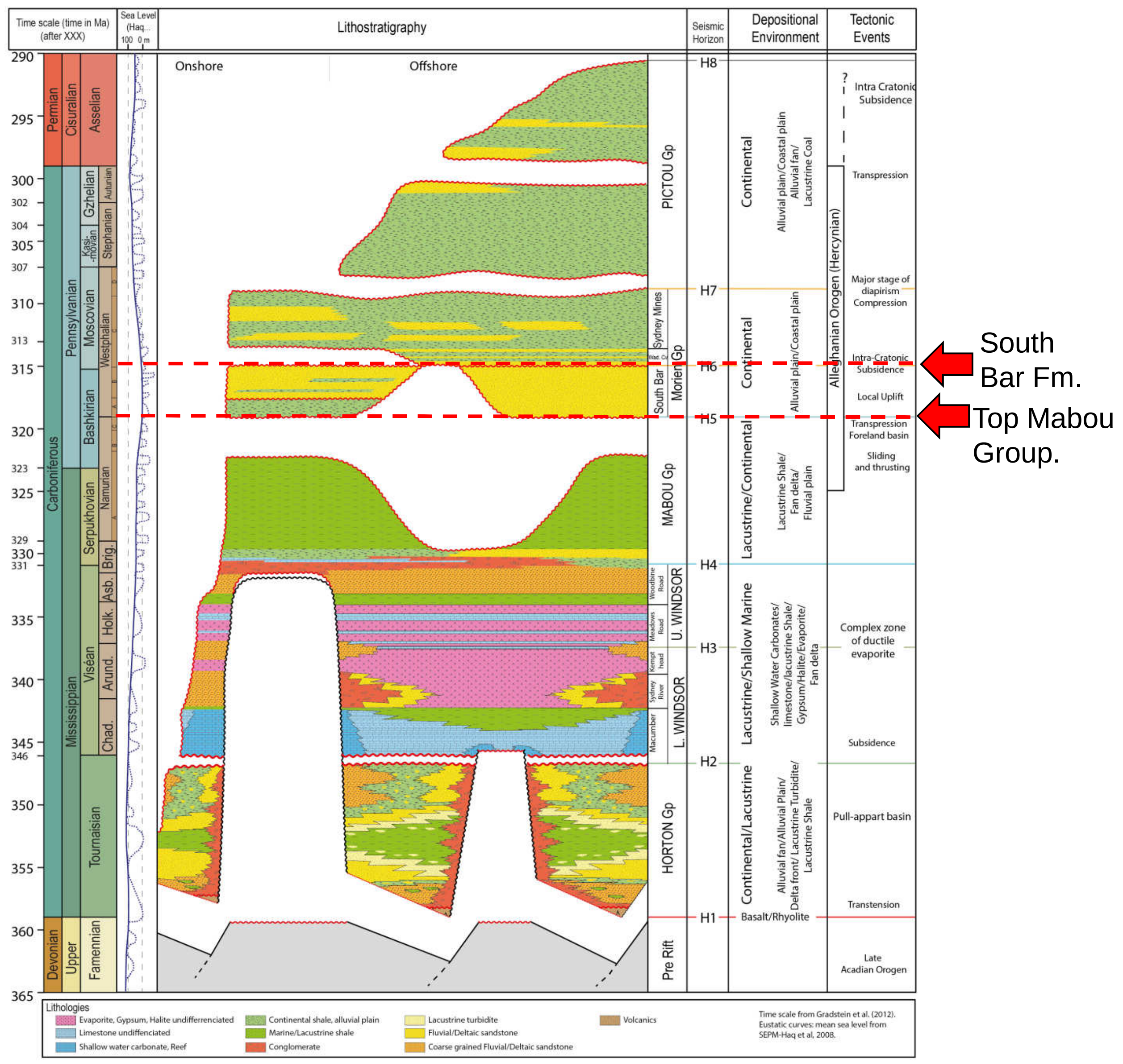
The well to seismic tie is not constrained at Saint Paul P-91 as the stratigraphic records start 610m MD in the Mabou Formation. Top Sydney Mines is the shallowest horizon tied with the offshore North Sydney wells P9 and F24.

Seismic Picking and Uncertainty

The lateral extrapolation of the Top Sydney Mines Formation away from the North Sydney wells is uncertain due to the presence of multiples and the fact that the Sydney Mines Formation is sometimes eroded by the Base Mesozoic and Pictou Unconformities.

Sydney Mines Formation

Tectono-Stratigraphical Chart



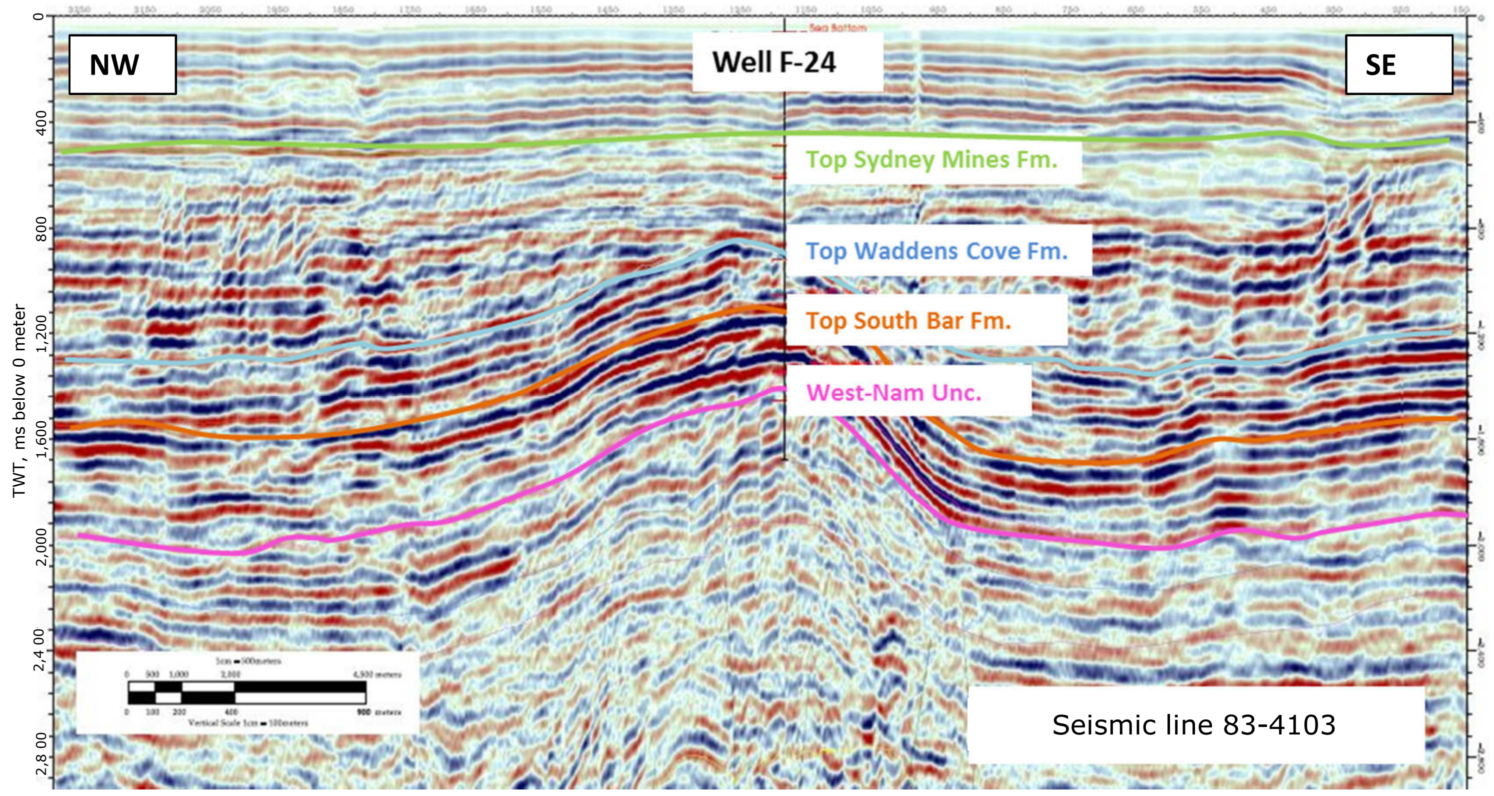


Figure 1: The Waddens Cove and South Bar Fms tied to the North Sydney well F24 markers. See seismic line locations on Figure 4.

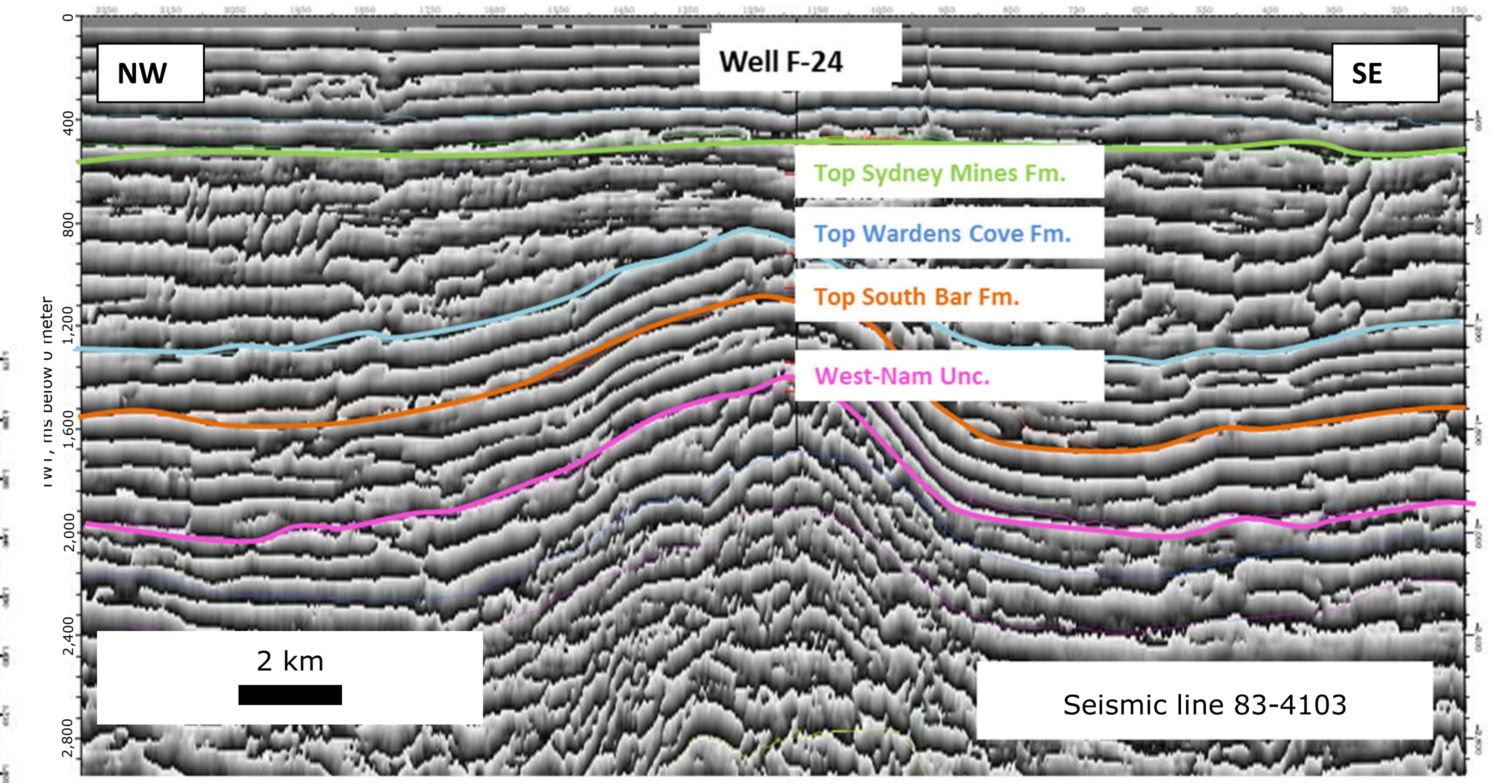


Figure 2: Seismic expression of the Waddens Cove and South Bar Fms on instantaneous phase. It displays enhancing onlaps on the top of the Wardens Cove Fm and truncations beneath the West-Namurian Unc.

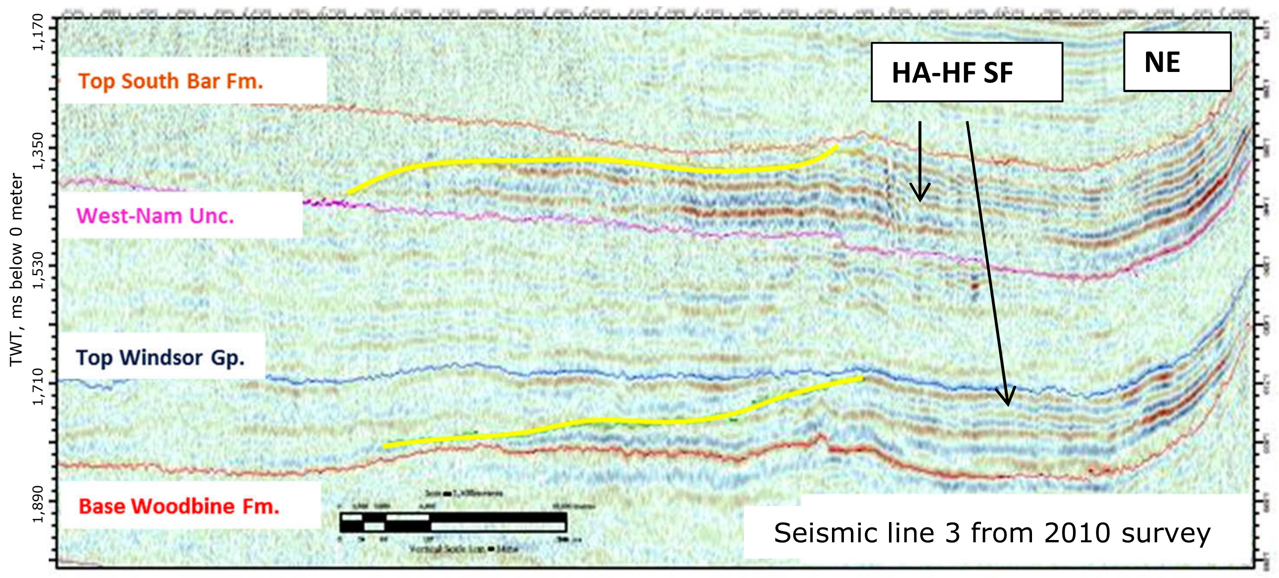


Figure 3: Lateral change in seismic facies across the yellow line from transparent to high amplitude – high frequency in the South Bar Fm. It is unclear whether the facies changes are real or due to noise. See seismic line locations on Figure 4.

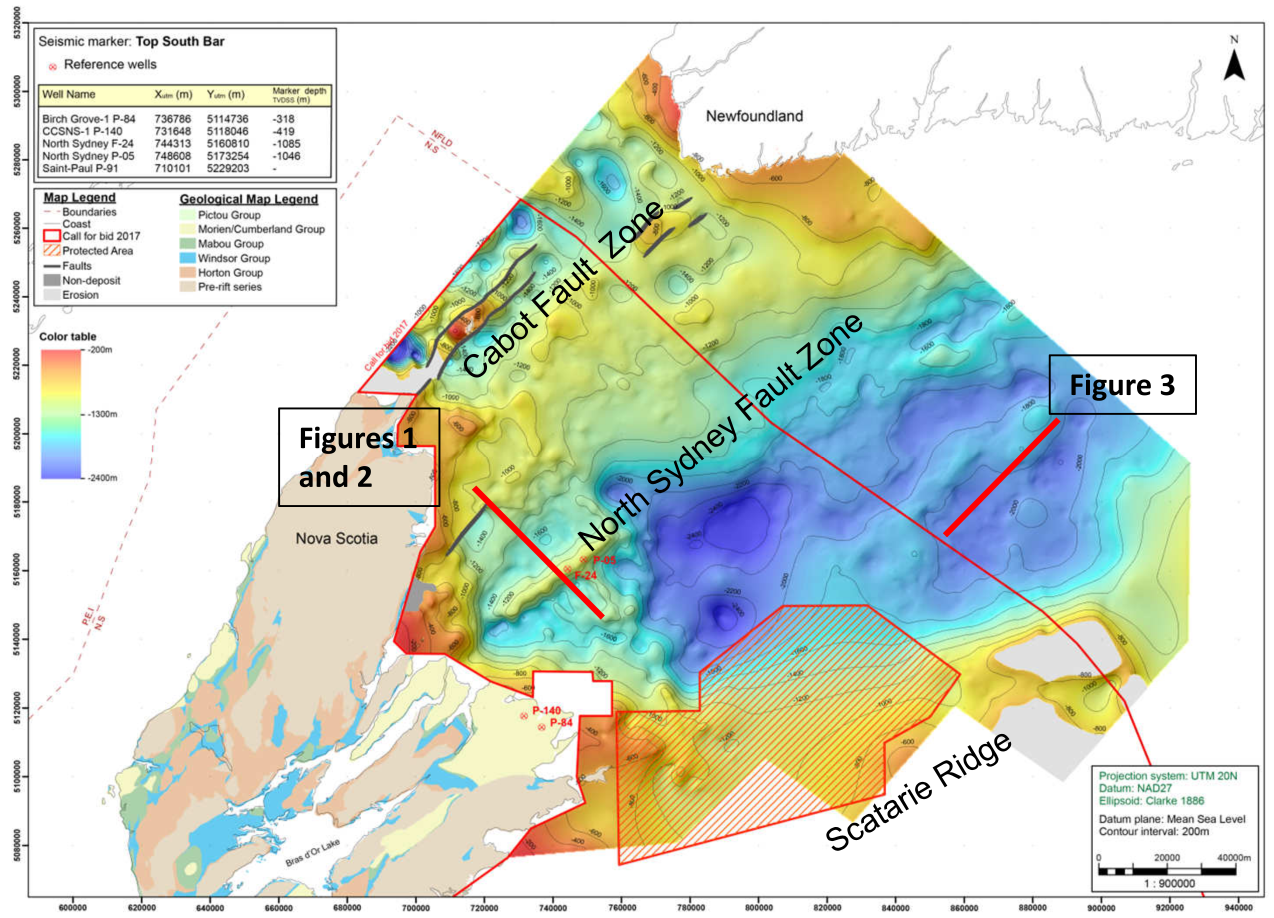


Figure 4: Depth (TVDSS) Map of Top South Bar Formation showing the Sydney Basin depocenter located over the North Sydney Fault Zone.

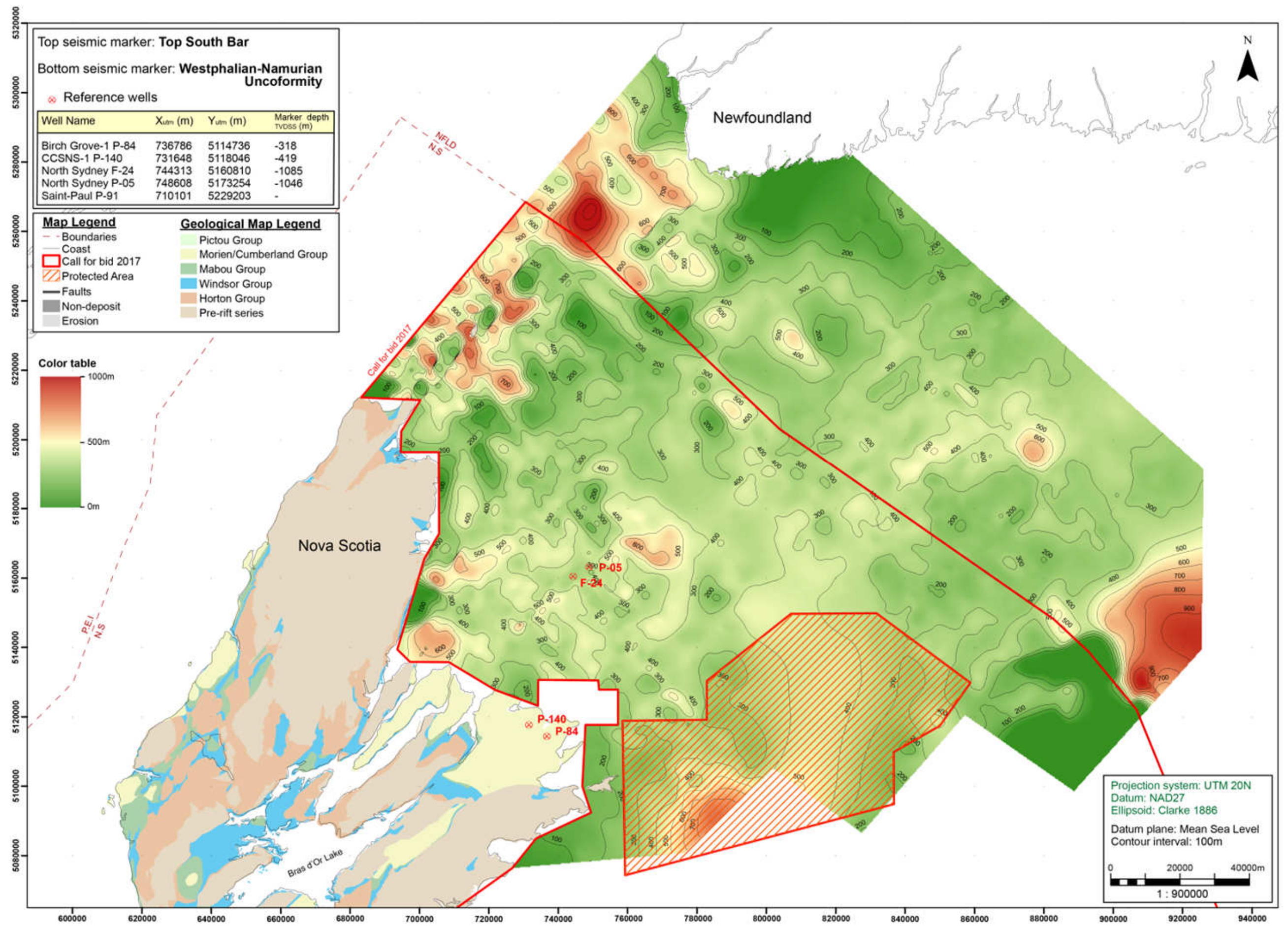


Figure 5: Thickness map of the South Bar Formation mostly isopach except along the Cabot destral strike slip fault zone and along Scatarie Ridge.

Horizon Definition and Structural Description

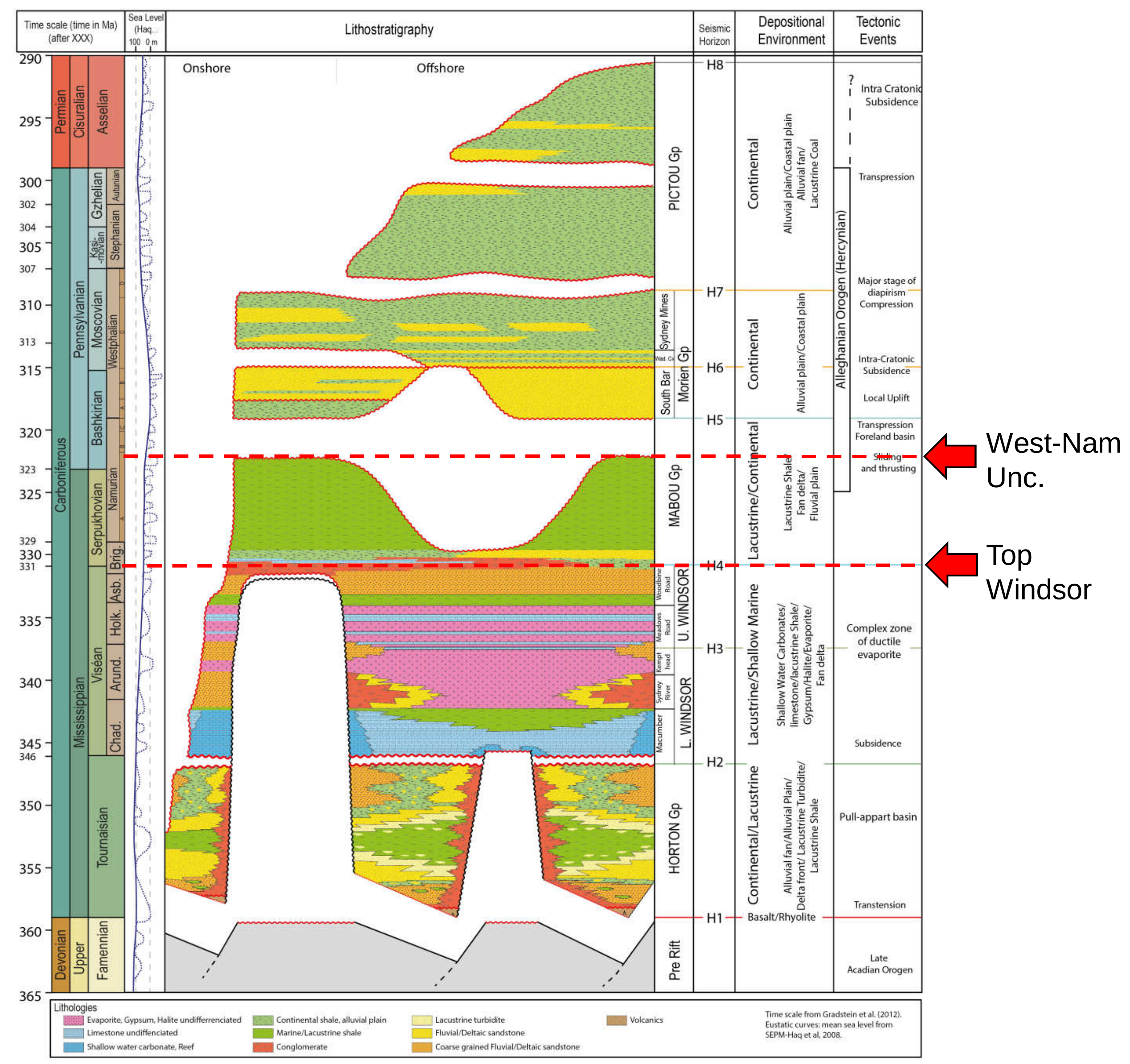
The horizon named "Top South Bar Fm." is an surface corresponding to the top of a continental series (Figures 1 and 2). The age of this surface has been estimated at 315 million years. Although the South Bar Formation is known to be represented by massive sandstones (outcrops and wells sampled on highs), the presence of high amplitude and high frequency seismic facies suggest the possible presence of coal seams in the depositional lows as observed on seismic line 8624-T007-006E-I 5 (Figure 2 on the previous plate). Use of instantaneous phase emphasizes the unconformity displayed through enhancement of onlaps and truncation at its base, and demonstrates the presence of multiple unconformities within the Cumberland Group continental strata. Among these, one of the main intra-Cumberland Group unconformities is observed at Top Waddens Cove Formation clearly visible on instantaneous phase display (Figure 2) showing the Waddens Cove strata onlapped by the Sydney Mines Formation.

Well to Seismic Tie: The well to seismic tie is done using both North Sydney wells P9 and F24.

Seismic Picking and Uncertainty: The well to seismic tie is acceptable at that level, but horizon propagation away from wells is affected by the presence of multiples over most seismic vintages.

The lateral extrapolation away from the wells was aided by the high amplitude – high frequency seismic facies that seem characteristic of the South Bar Formation. Nevertheless, lateral seismic facies changes are observed within the South Bar Fm.

Tectono-Stratigraphical Chart



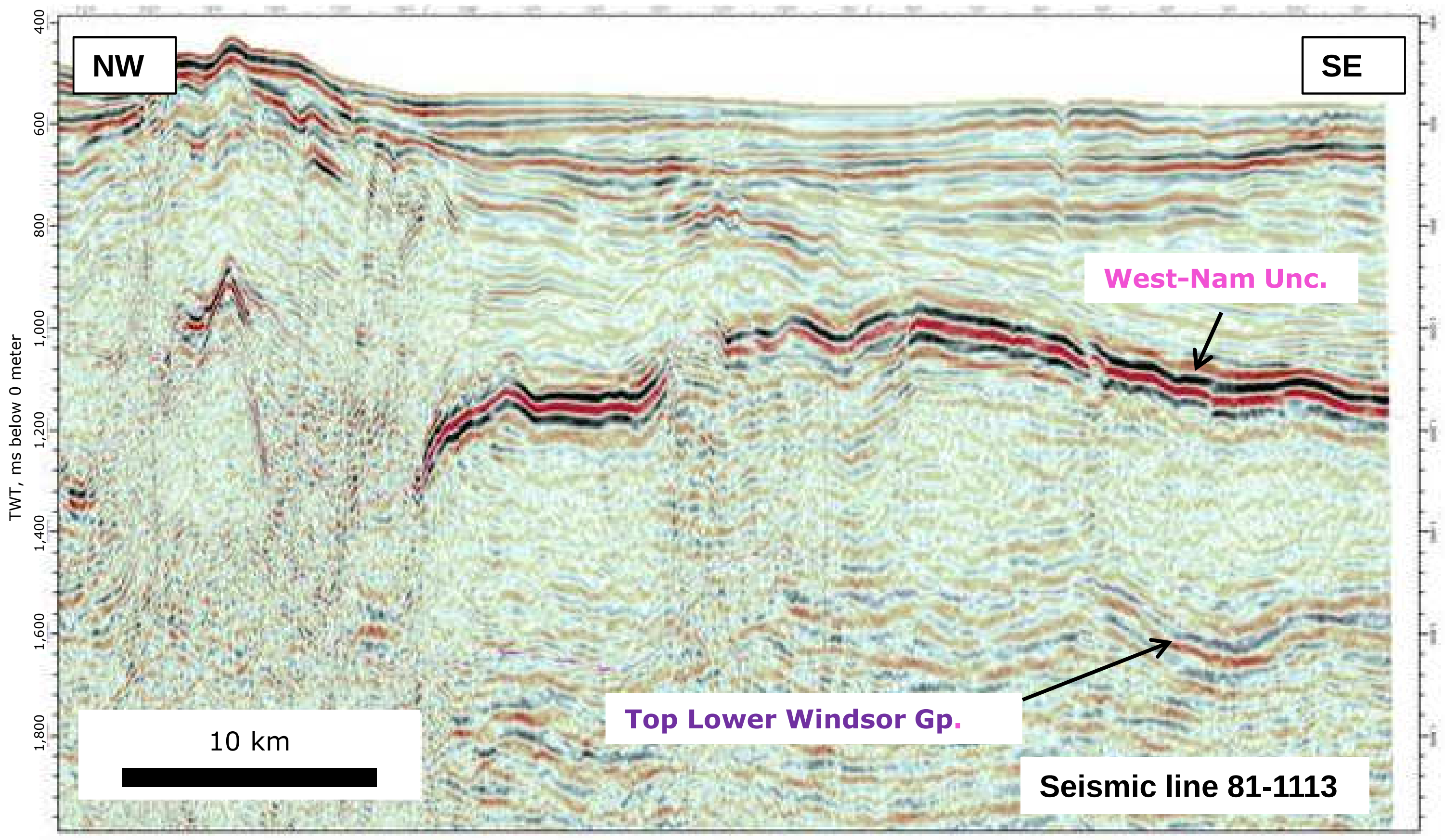


Figure 1: Seismic expression of the Westphalian-Namurian Unconformity eroding the Mabou Group shown on a set of displays of seismic line 81-1113 (reflectivity data version). See seismic line locations on Figure 4.

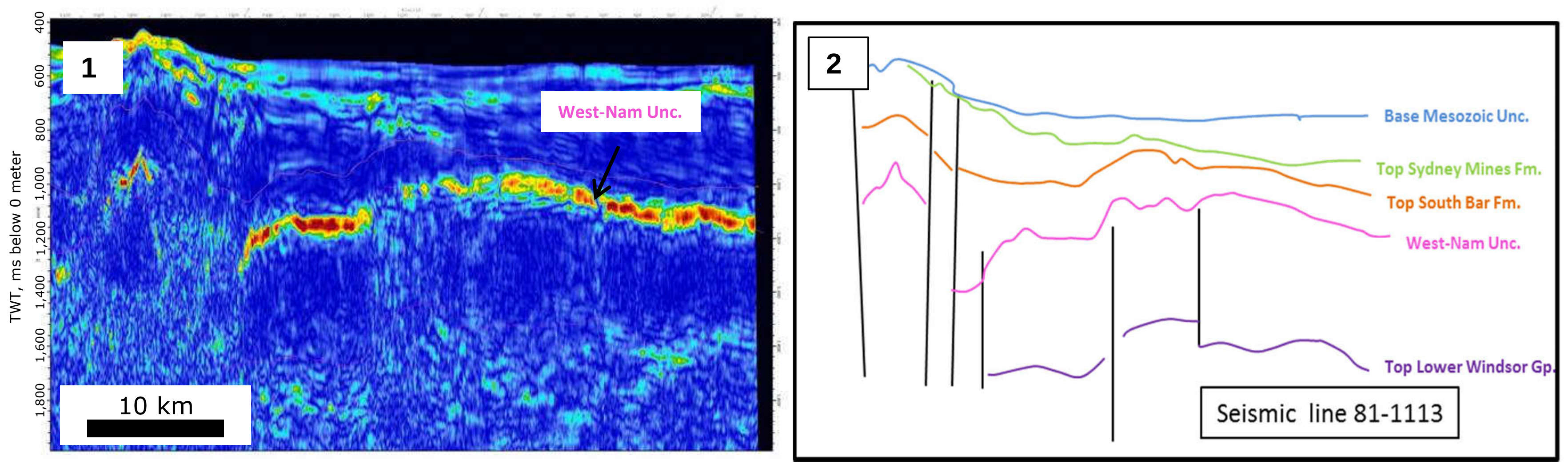


Figure 2: Seismic expression of the Westphalian-Namurian Unconformity eroding the Mabou Group shown on a set of displays of seismic line 81-1113. Figure 2-1: reflectivity strength; Figure 2-2: horizons and fault interpretation.

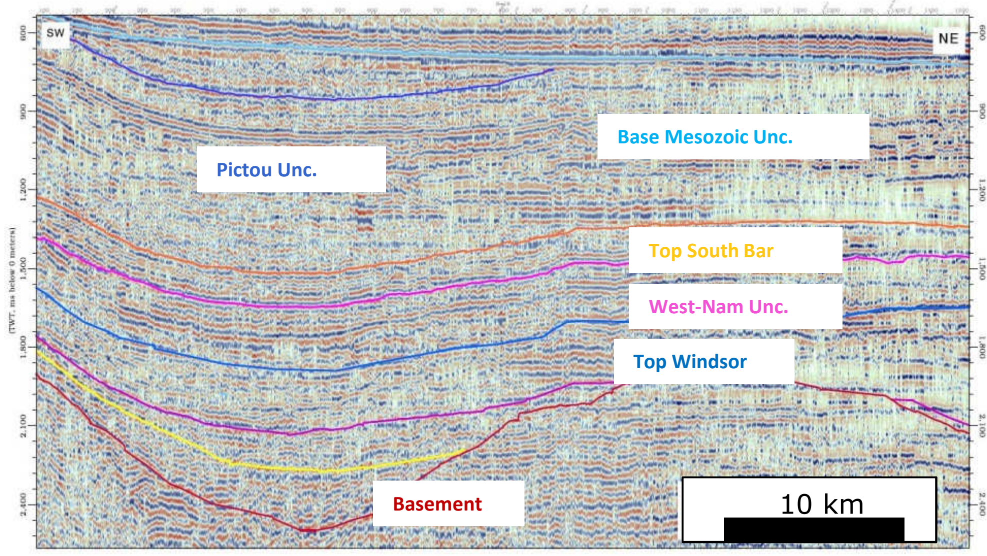


Figure 3: The Westphalian-Namurian Unconformity is represented by a minor unconformity (line R-18)

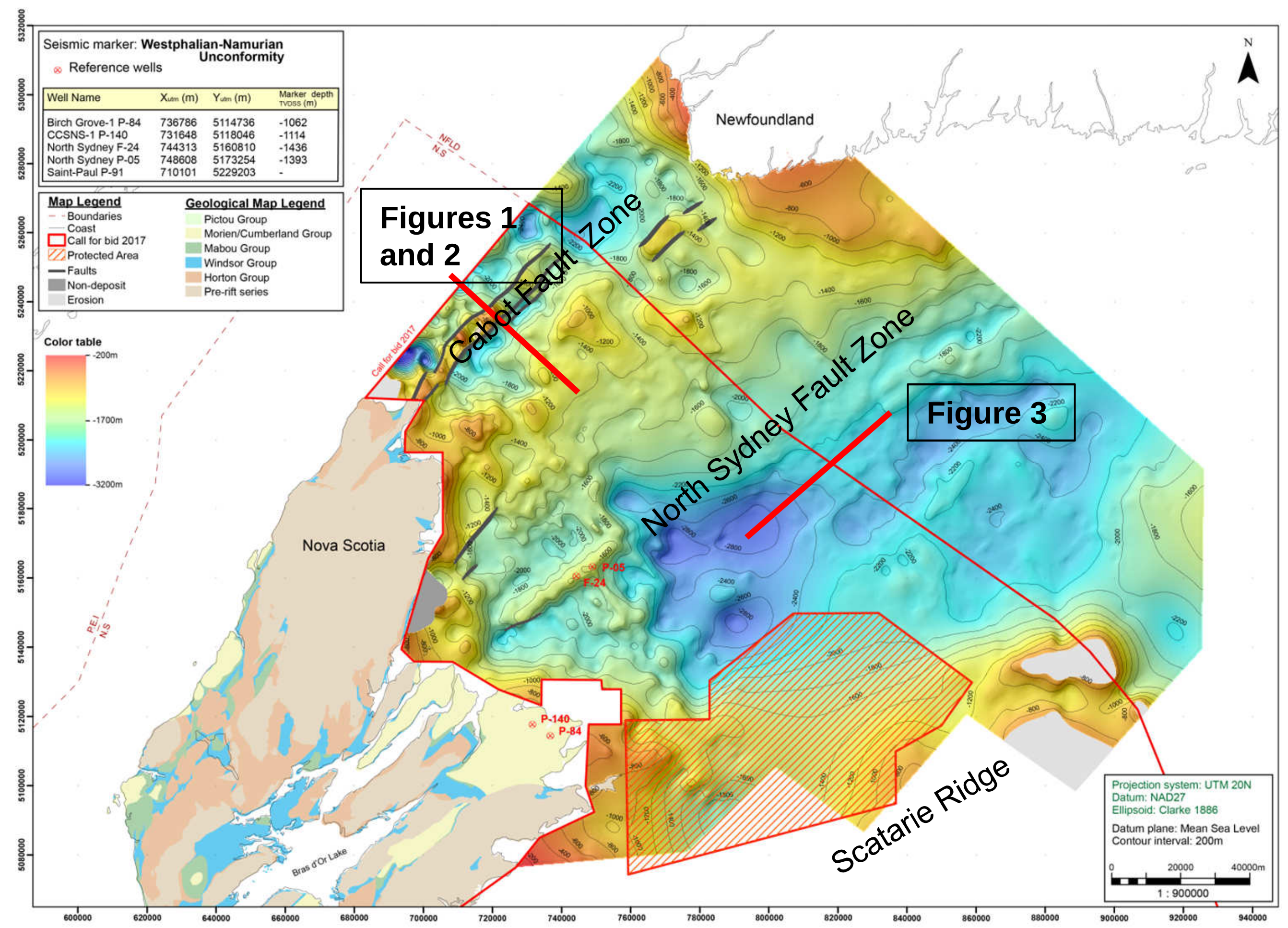


Figure 4: Depth (TVDSS) Map of Westphalian-Namurian Unconformity eroding older strata down to the Basement, i.e. pre-rift series.

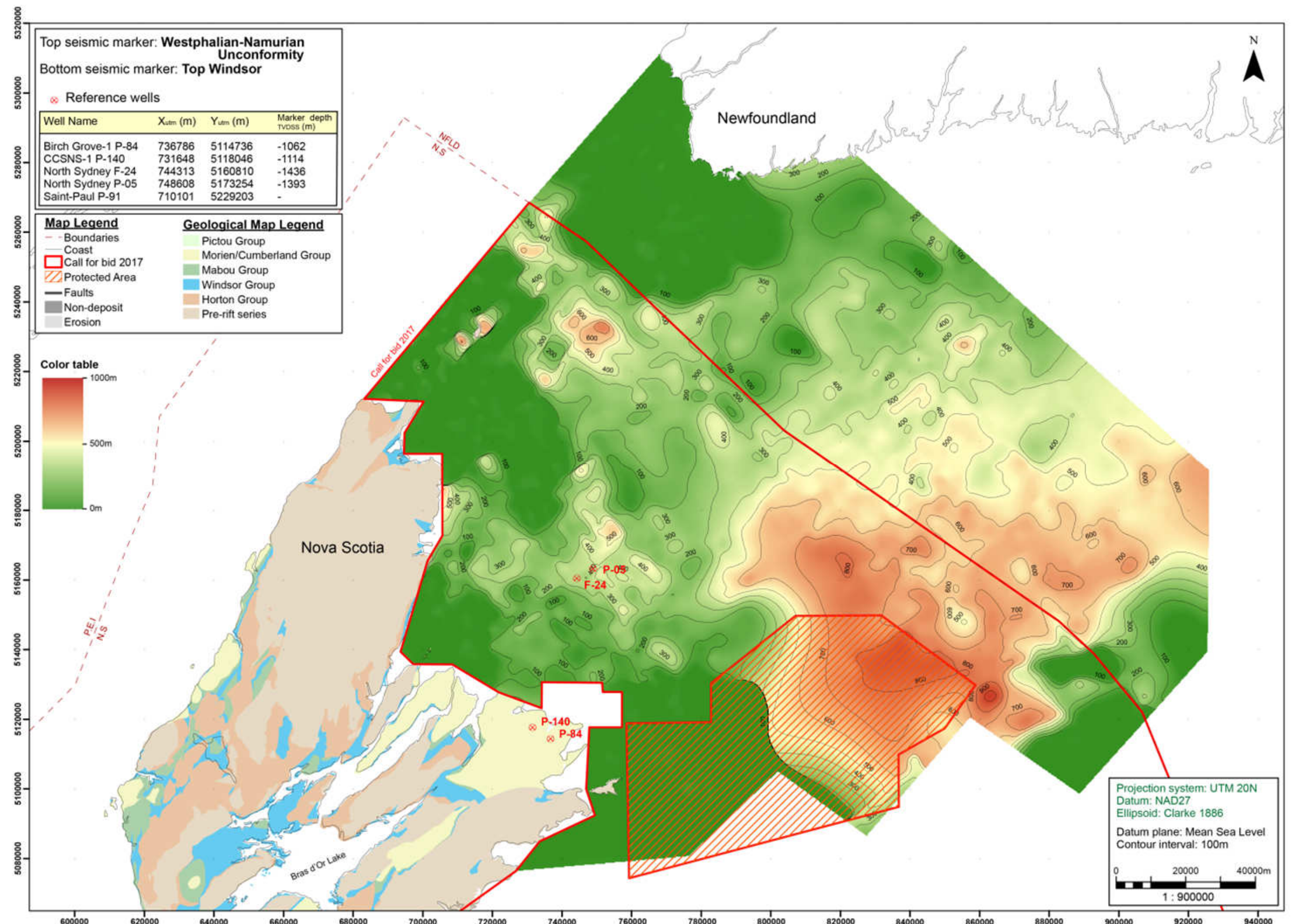


Figure 5: Thickness map of the Mabou Group beneath the Westphalian- Namurian Unconformity and Top Windsor Group showing that it is mostly preserved in the central part of the Sydney Basin.

Horizon Definition and Structural Description

The horizon named "Westphalian/Namurian Unconformity" is an erosional surface corresponding to the top of the Mabou Group represented by either the Point Edward or Cape Dauphin Formations. The age of this surface has been estimated at 323 million years. The Westphalian/Namurian Unconformity represents a major hiatus. In some areas the Westphalian - Namurian Unconformity has eroded all of the older strata down to the pre-rift series. Deep erosional features associated with a high impedance contrast reflector are present along the edges of the Sydney Basin as observed on seismic line 81-1113. Three displays of seismic line 81-1113 show interpretations of the entire suite of named horizons: Base Mesozoic Unconformity, Top Sydney Mines Formation, Top South Bar Formation, Westphalian/Namurian Unconformity, Top Windsor Group and Lower Windsor Group. Figures 1 and 2-1 show the high impedance contrast associated to the Westphalian - Namurian Unconformity. Toward the center of the Sydney Basin (i.e. away from the basin edges) the Westphalian/Namurian Unconformity passes to a disconformity difficult to trace with certainty in the main depocenter as shown on the reflectivity data display of seismic line R-18 (Figure 3). Further, it is losing its typical signature on the seismic lines affected by multiples. Lastly, the Mabou Gp. thickness map may suggest the possible presence of lacustrine strata deposited along the Scatarie Ridge.

Well to Seismic Tie

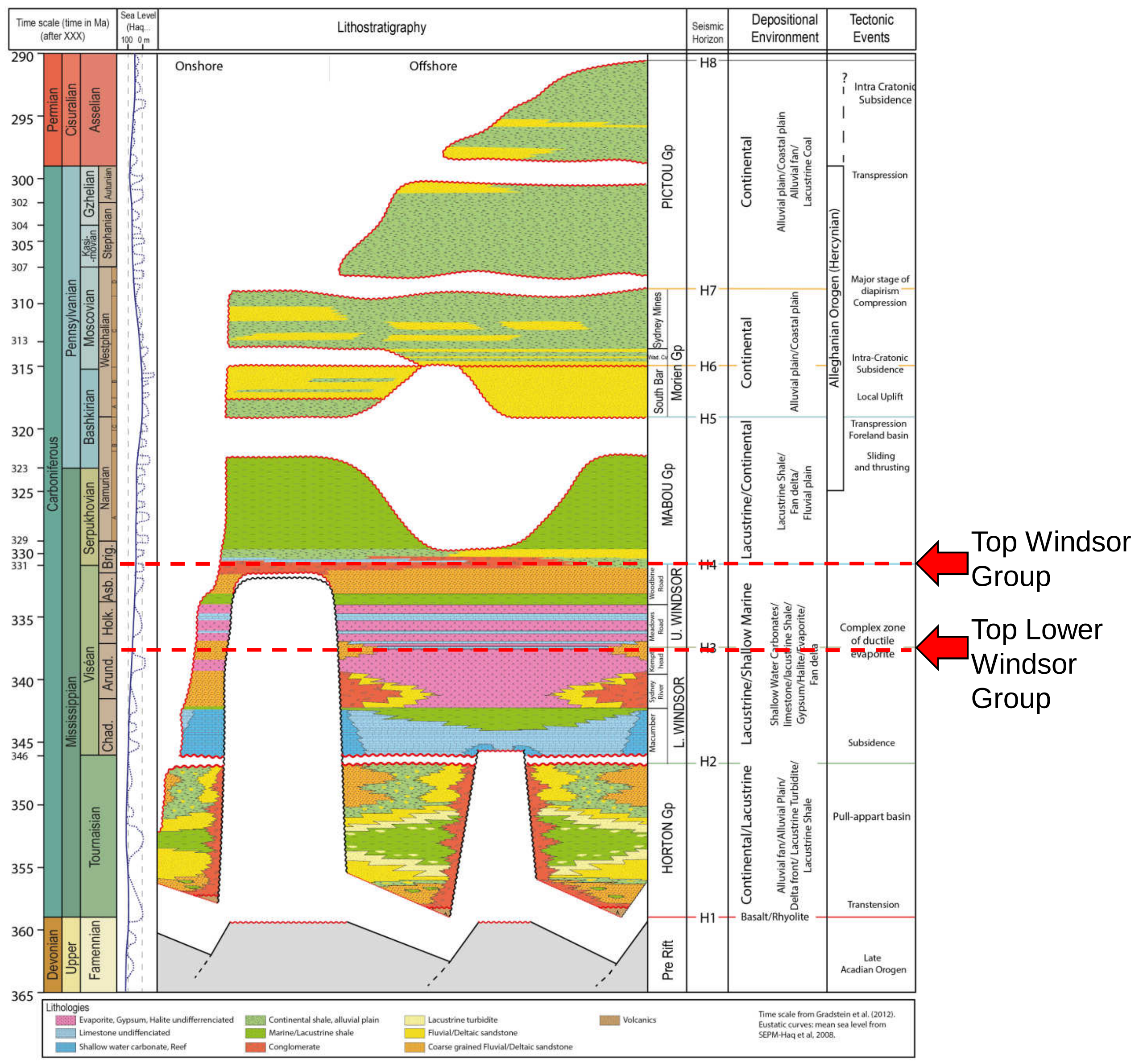
The well to seismic tie is done through both North Sydney wells P-05 and P-24.

Seismic Picking and Uncertainty

The lateral extrapolation of the Westphalian/Namurian Unconformity away from the wells was aided by its main feature: it is the primary unconformity in Carboniferous sediments, especially visible in 1981 and 1983 PetroCanada surveys, and also near the Cabot High on the Lithoprobe line. Deeper in the basin (2010 survey lines), it appears to become locally a conformable surface located at the transition between the Morien Group and the Mabou Group.

SEISMIC INTERPRETATION - STRUCTURAL MAPPING

Tectono-Stratigraphical Chart



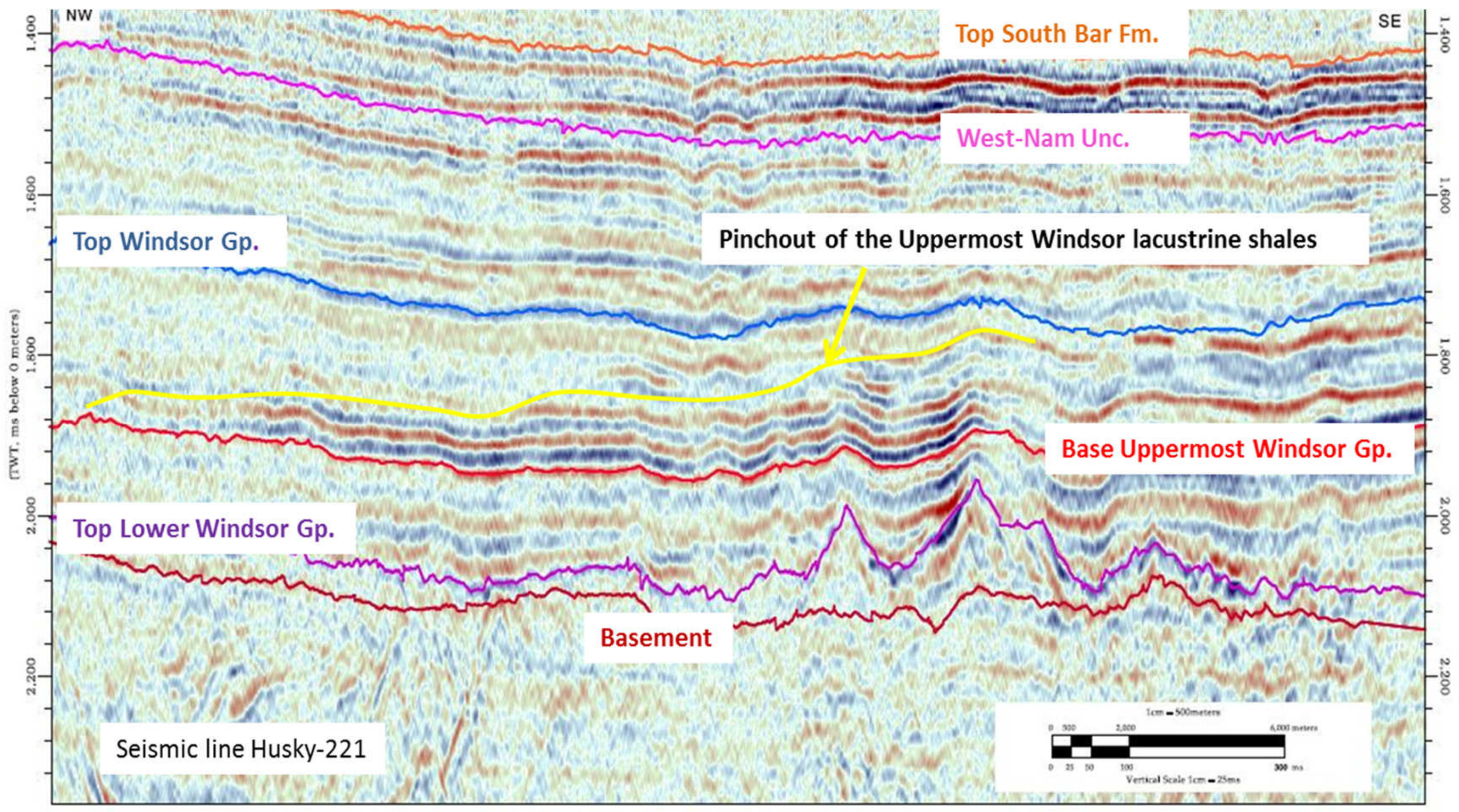


Figure 1: Reflection data display of the 2010 seismic line survey (location Figure 3). The Uppermost Windsor Group shows a series of high amplitude – high frequency continuous reflections tentatively delineated and interpreted as shallow marine shales. Figures 1 and 2 are displayed at the same scale (see Figure 2). Seismic line locations are shown on Figure 3.

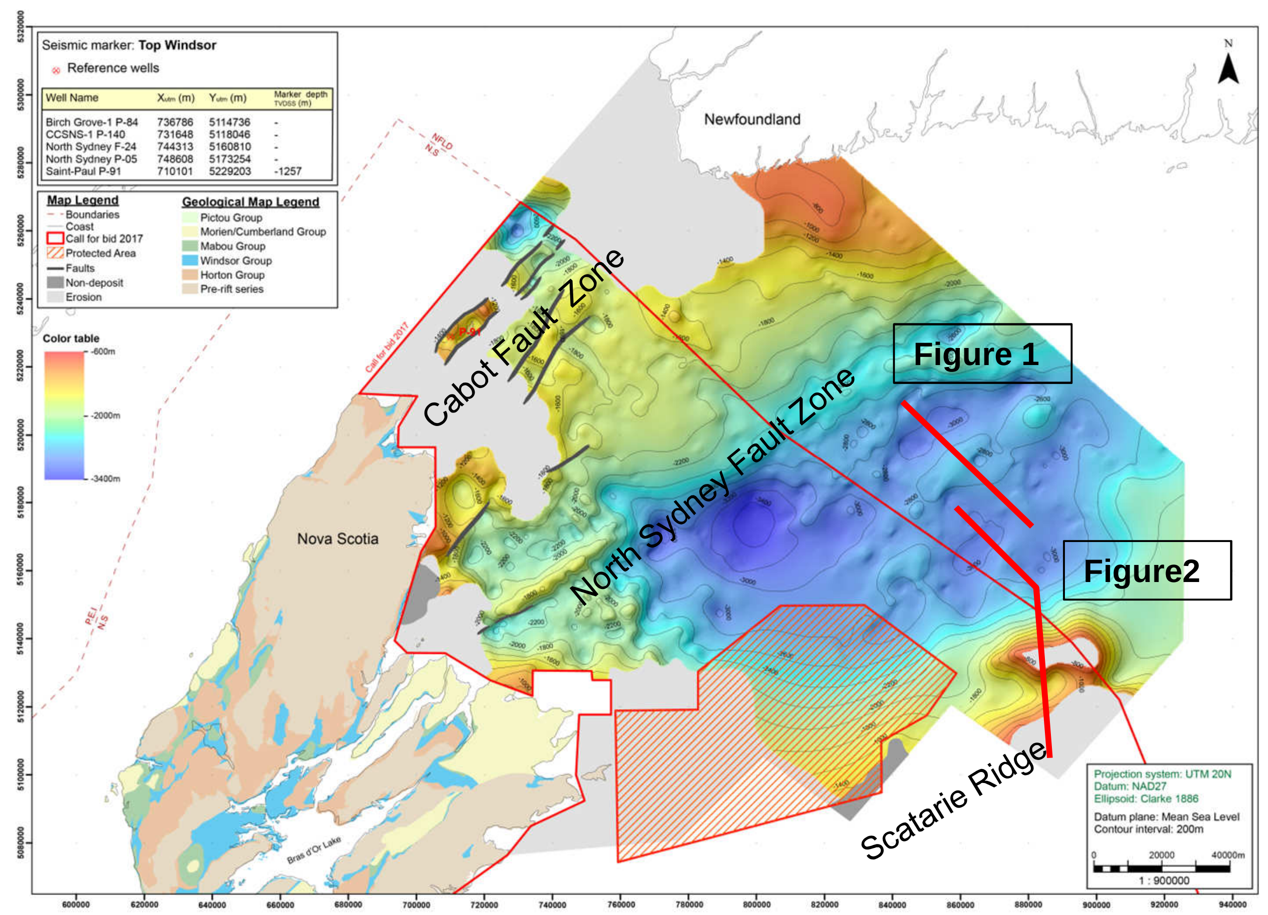


Figure 3: Depth (TVDSS) Map of Top Windsor Group showing the imprint of the North Sydney fault zone over the Sydney Basin. Light grey represents areas where the Top Upper Windsor is eroded by the West Namurian Unc, but the erosion is incomplete preserving part of the Top Windsor thickness (see below).

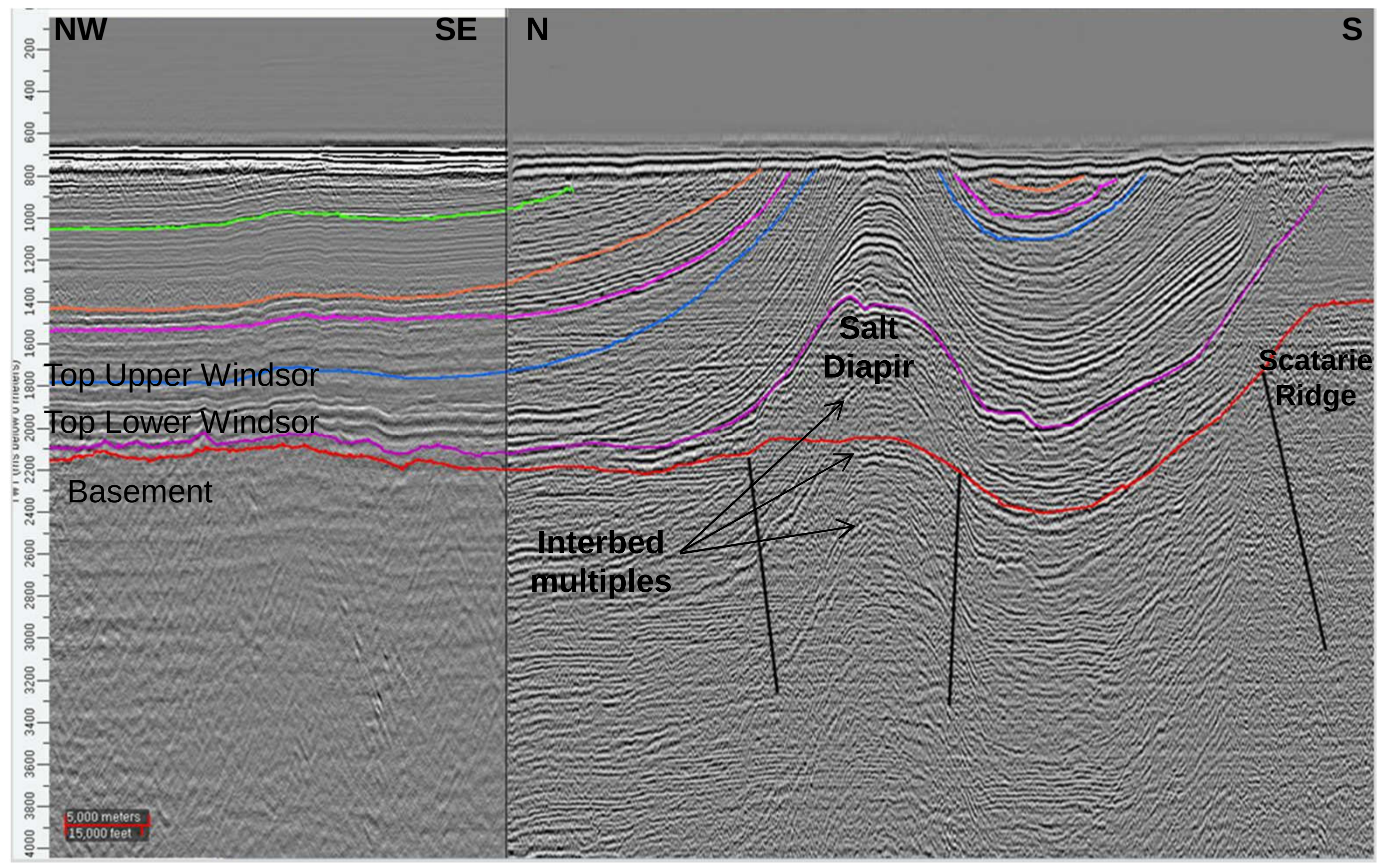


Figure 2: Seismic transect showing thickening of the Windsor Gp. towards Scatarie Ridge. Facies transition is expected to be from shallow water carbonate on top of basement structure (see also Figure 1) to a shallow marine environment as imaged by the presence of salt and high amplitude – high frequency continuous reflections above the Top Lower Windsor. Composite seismic line locations are shown on Figure 3.

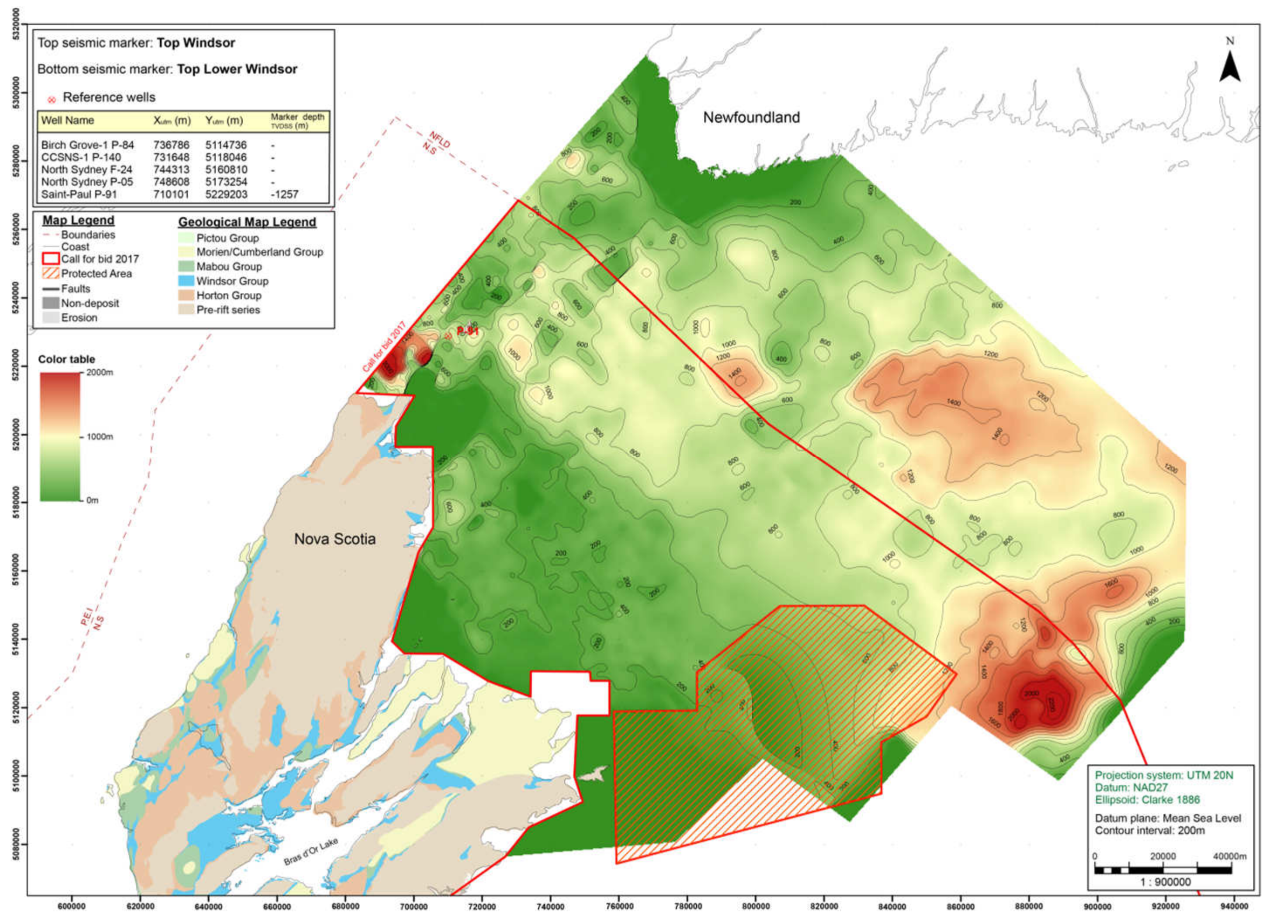


Figure 4: Thickness map of the Upper Windsor Group showing two depocenters, one along the Burgeo High and the other along Scatarie Ridge.

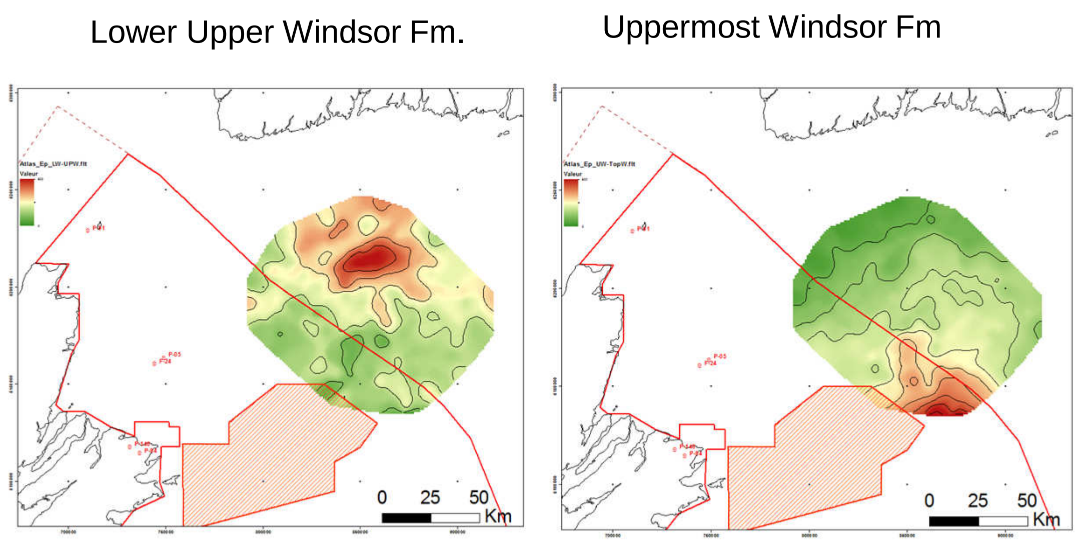


Figure 6: Isochrone map of the Upper Windsor Fms: The Uppermost Windsor Fm. (map to the right and unit between top Windsor Group and the red horizon on Figures 1 and 2) resting over the Lower Upper Windsor Fm. (map to the left and unit between the red horizon and top Lower Windsor Group) shows a southward depocenter shift.

Horizon Definition and Structural Description

The horizon named "Top Windsor Group" corresponds to the top of the Woodbine Road Formation in the center of the Sydney Basin or lateral equivalent of the Upper Windsor Formations. The age of this surface has been estimated at 331 million years. The Top Windsor Group is associated with an average impedance contrast reflector as observed on Figures 1 and 2. Instantaneous phase displays enable the picking of truncations and onlaps, and show clear lateral seismic facies changes within the Woodbine Road Formation, from transparent seismic facies toward higher amplitude and higher frequency seismic facies.

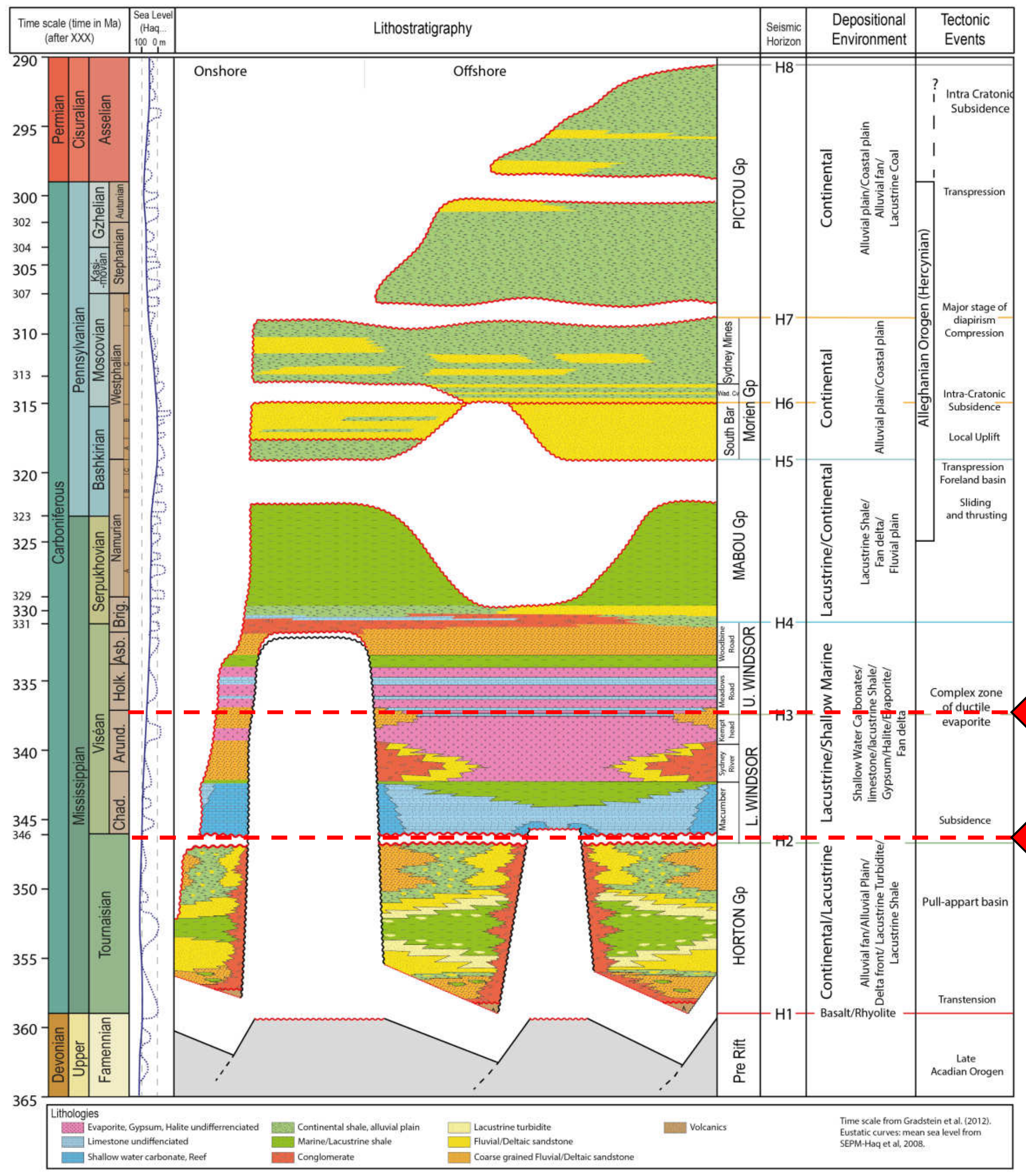
Well to Seismic Tie and Seismic Picking Uncertainty

None of the North Sydney wells have penetrated the Windsor Group. Well P-91 is the only well that penetrated the top of the Windsor Group. Well P91 reached the Sydney River Formation within the Lower Windsor Group. Nevertheless its position over the Saint Paul High does not allow the propagation of the Top Windsor horizon on either side of this block with confidence.

Top Windsor Group has been picked along a horizon representing an unconformity. Toward the edges of the Sydney Basin, the upper Windsor is partly eroded by the Westphalian/Namurian Unconformity. On the 2010 seismic survey, an additional horizon could be picked within the Upper Windsor attributed to the base Uppermost Windsor Group. Observed lateral seismic facies variation can be mapped in the center of the Sydney Basin as shown on Figures 1 and 2. Location of transparent versus high amplitude – high frequency seismic facies are interpreted as representing respectively continental or stratified marine strata as shown on Figures 1 and **2**. Comparison between the Uppermost Windsor Group and Lower Upper Windsor Group - respectively equivalent to the "Woodbine Road and Meadows Road Formations" - thickness maps shows a southward shift of the Upper Windsor depocenter (Figure 6). It's notable that the structural map (Figure 3) is missing part of the Top Windsor, whereas the thickness map (Figure 4) shows a complete record. This is due to the fact that it is not because a top Fm is lacking that the entire series is eroded. Here the Top Windsor is eroded by the overlaying formation, but upper Windsor sediments do exist in this area as suggested by the outcrops along the coast.

SEISMIC INTERPRETATION - WELL TO SEISMIC CALIBRATION

Tectono-Stratigraphical Chart



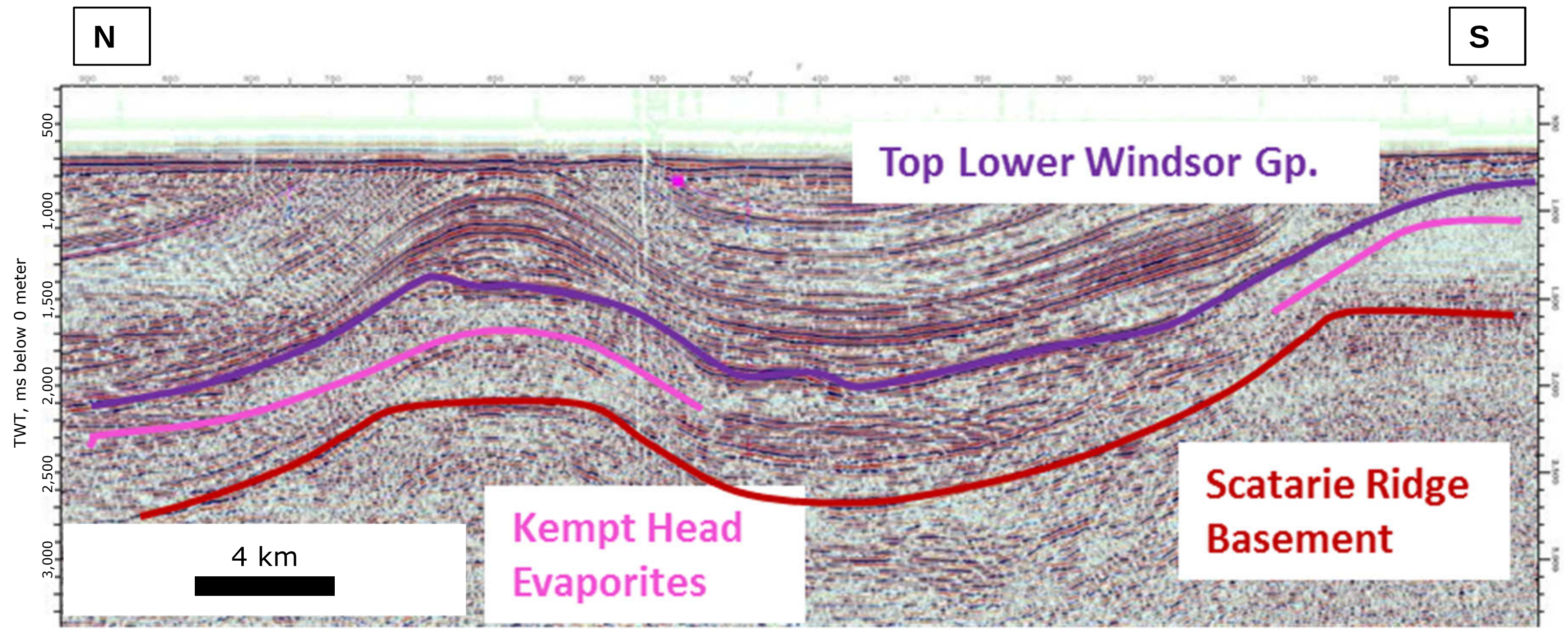


Figure 1: Seismic expression of the Lower Windsor Group on seismic line 8624-T007-006E-F. The evaporites of the Kempt Head Fm. are represented by a salt diapir along Scatarie Ridge. See seismic line location on Figure 3.

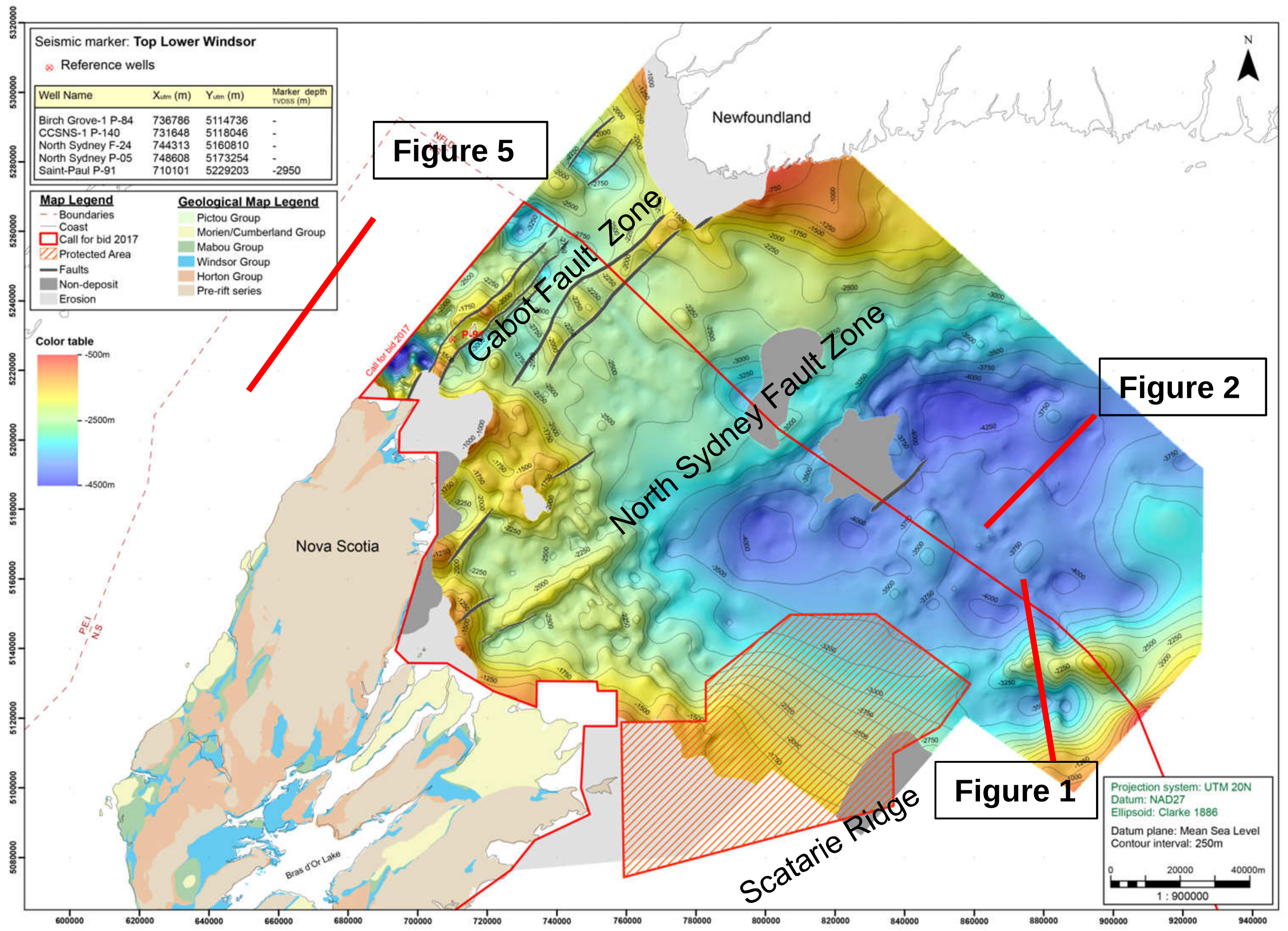


Figure 3: Depth (TVDSS) map of Top Lower Windsor Group showing the Lower Windsor Group depocenter located between the North Sydney Fault zone and Scatarie Ridge.

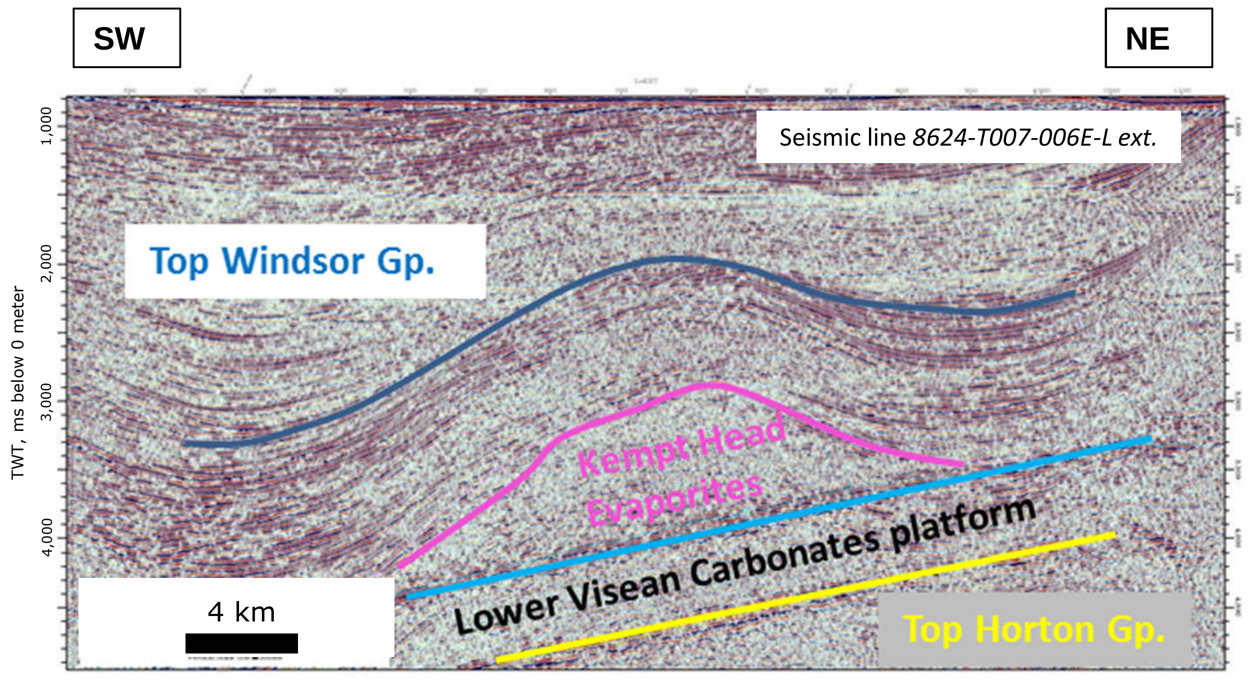


Figure 5: Seismic expression of the Lower Windsor Group salt dome on seismic line 8624-T007-006E-L ext., resting over the Lower Visean shallow-water carbonates platform in the Magdalena Basin, east of the Cabot Fault Zone. See seismic line location on Figure 3.

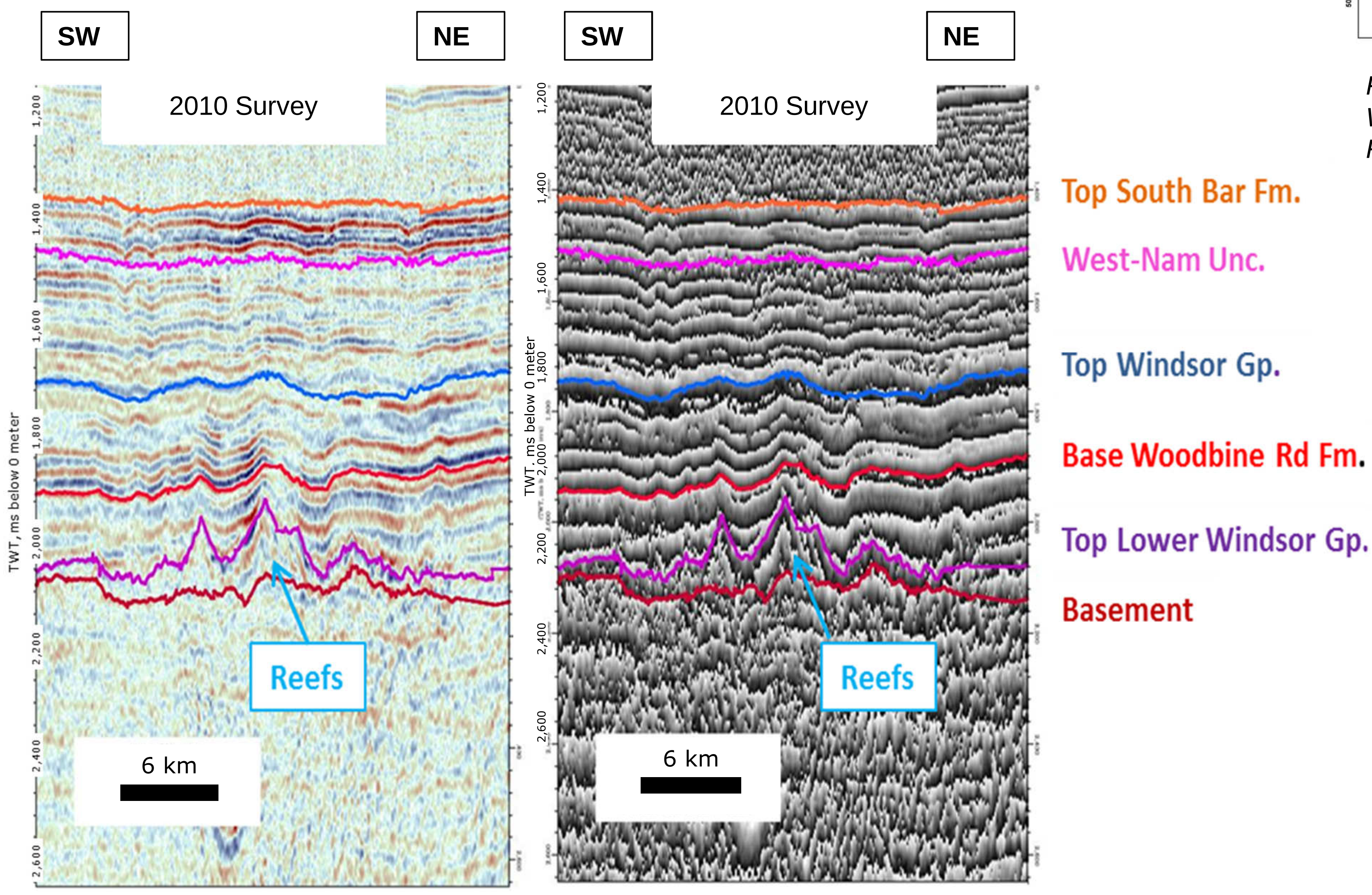


Figure 2: Seismic expression of carbonate build-ups on reflectivity and instantaneous phase displays. It is developed over a basement high and onlapped by Upper Lower Windsor Group. See seismic line location on Figure 3.

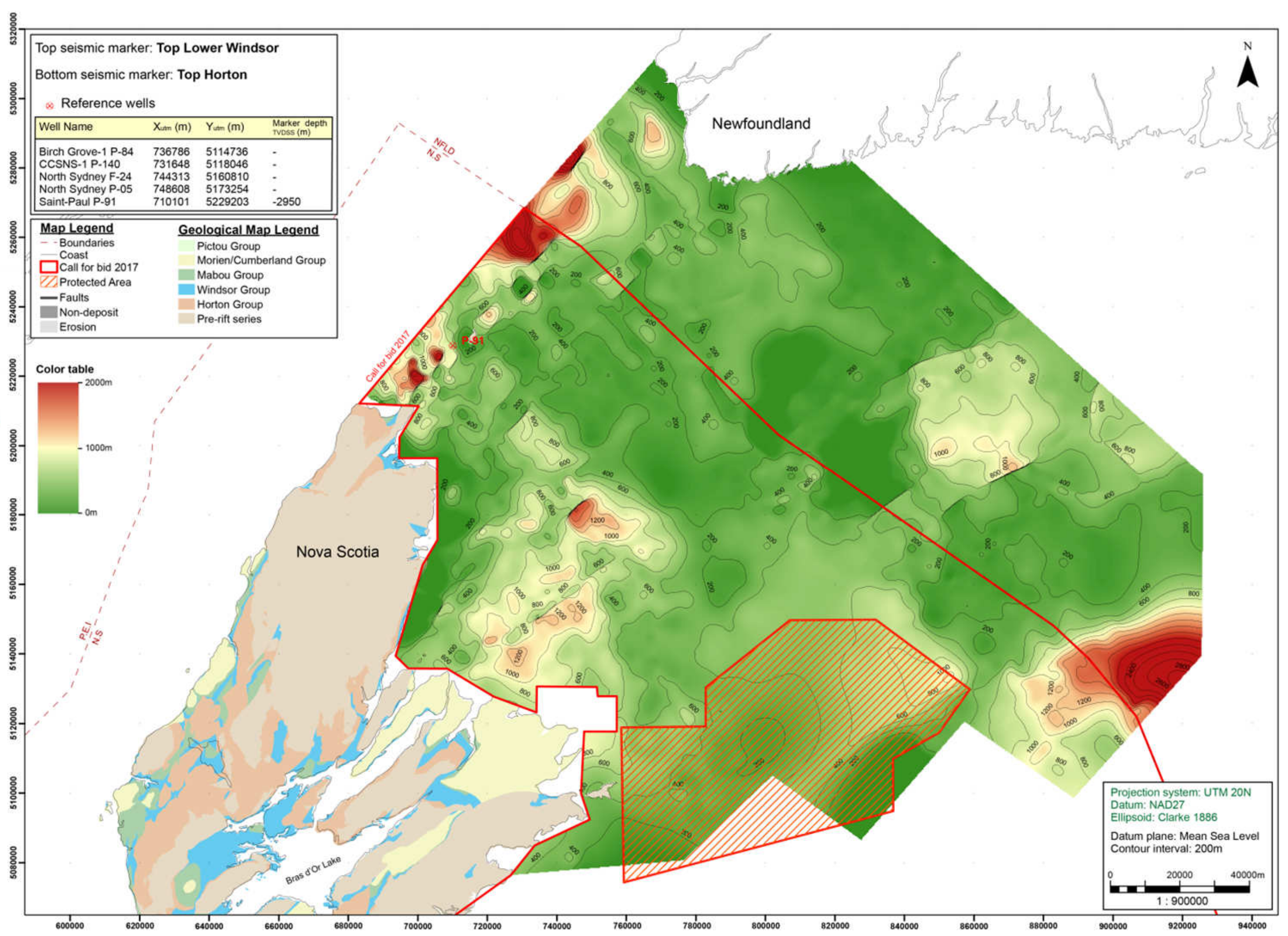


Figure 4: Thickness map of the Lower Windsor Group showing depocenters in the Searston deep pull-apart basin within the Cabot Fault Zone, along the North Sydney Fault Zone and Scatarie Ridge.

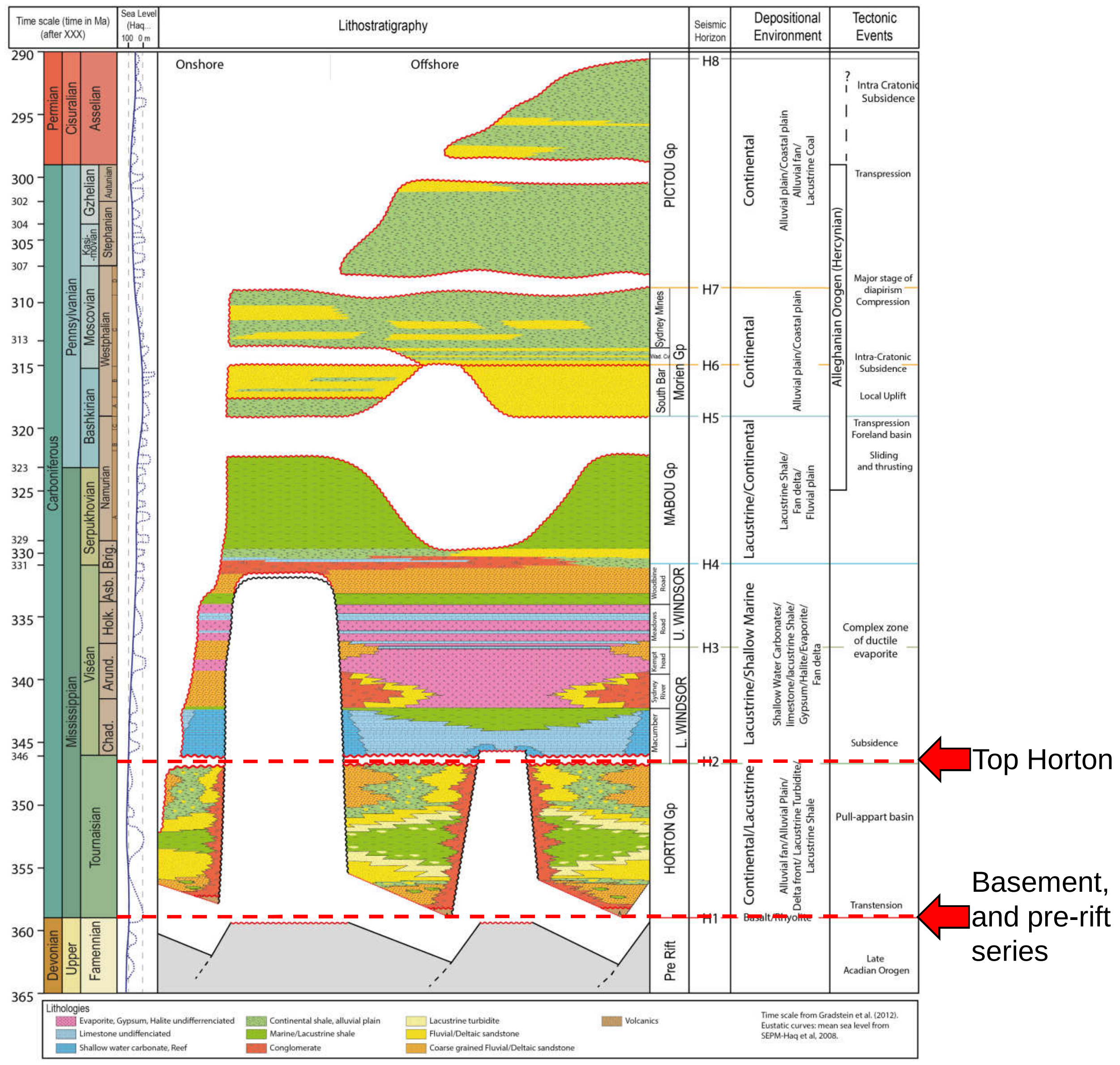
Horizon Definition and Structural Description

The horizon named "Top Lower Windsor " is a conformal surface represented by an evaporitic series. It is interpreted as locally representing the top of a salt diapir. The Lower Windsor Group represents the base of the Visean marine transgression deposited during thermal subsidence that post-dates Tournaisian rifting. The age of this surface has been estimated at 337 million years. The presence of salt diapirs can be observed along the SE edge of Sydney Basin, i.e. Scatarie Ridge and Burin Platform (Figure 1). There are also a number of salt diapirs along the Cabot Fault Zone. The typical transparent seismic facies associated with thick evaporites could not be delineated as it is obscured by the presence of numerous multiples. The series of high amplitude – high frequency continuous reflections at the base of the diapirs are interpreted as representing a shallow water carbonate platform. Figure 2 shows carbonate build-ups or reefs resting on the basement high. In the neighbouring Magdalen Basin, Figure 5 shows a clear example of a salt diapir resting over the Lower Visean shallow water carbonate platform.

Well to Seismic Tie and Seismic Picking Uncertainty

St Paul P91 is the only well that has sampled the Lower Windsor but because of successive erosion it is impossible to laterally propagate the horizon from the well. The seismic picking is entirely based on seismic character and reflection configurations through comparison between seismic vintages within the Sydney Basin and neighboring Magdalen Basin. For comparison, seismic line 8624-T007-006E-L ext (Figure 5) shows the seismic expression of the Lower Windsor Group further east in the Magdalen Basin where a prominent salt dome is resting over the Lower Visean shallow water carbonates platform. It can be observed that the Lower Visean carbonate platform is better defined in the Magdalen Basin than in Sydney Basin.

Tectono-Stratigraphical Chart



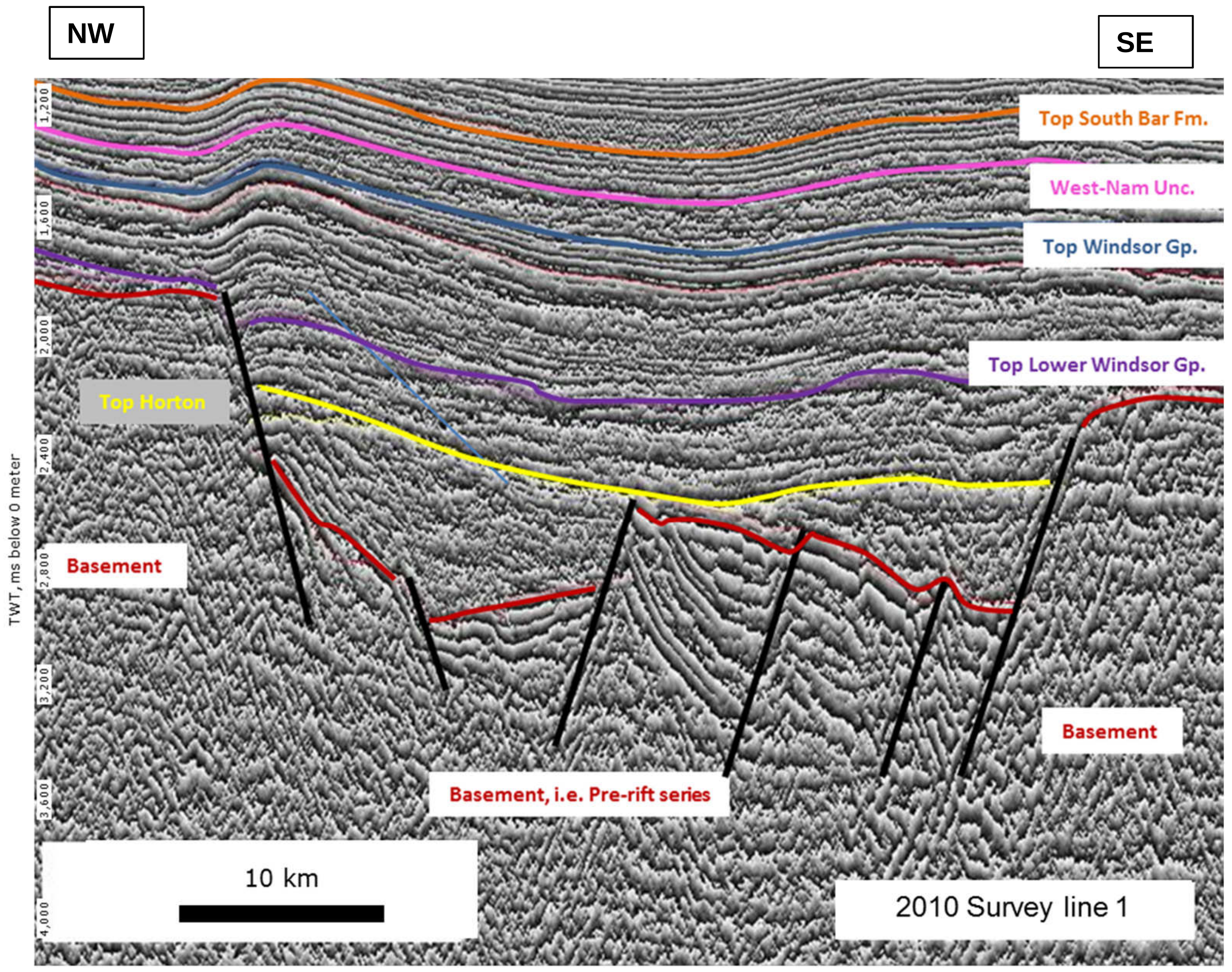


Figure 1: Seismic expression of the Horton Group. The instantaneous phase display shows that Top Horton is an unconformity through the presence of truncations underneath it and onlaps above it. See seismic line locations on Figure 3.

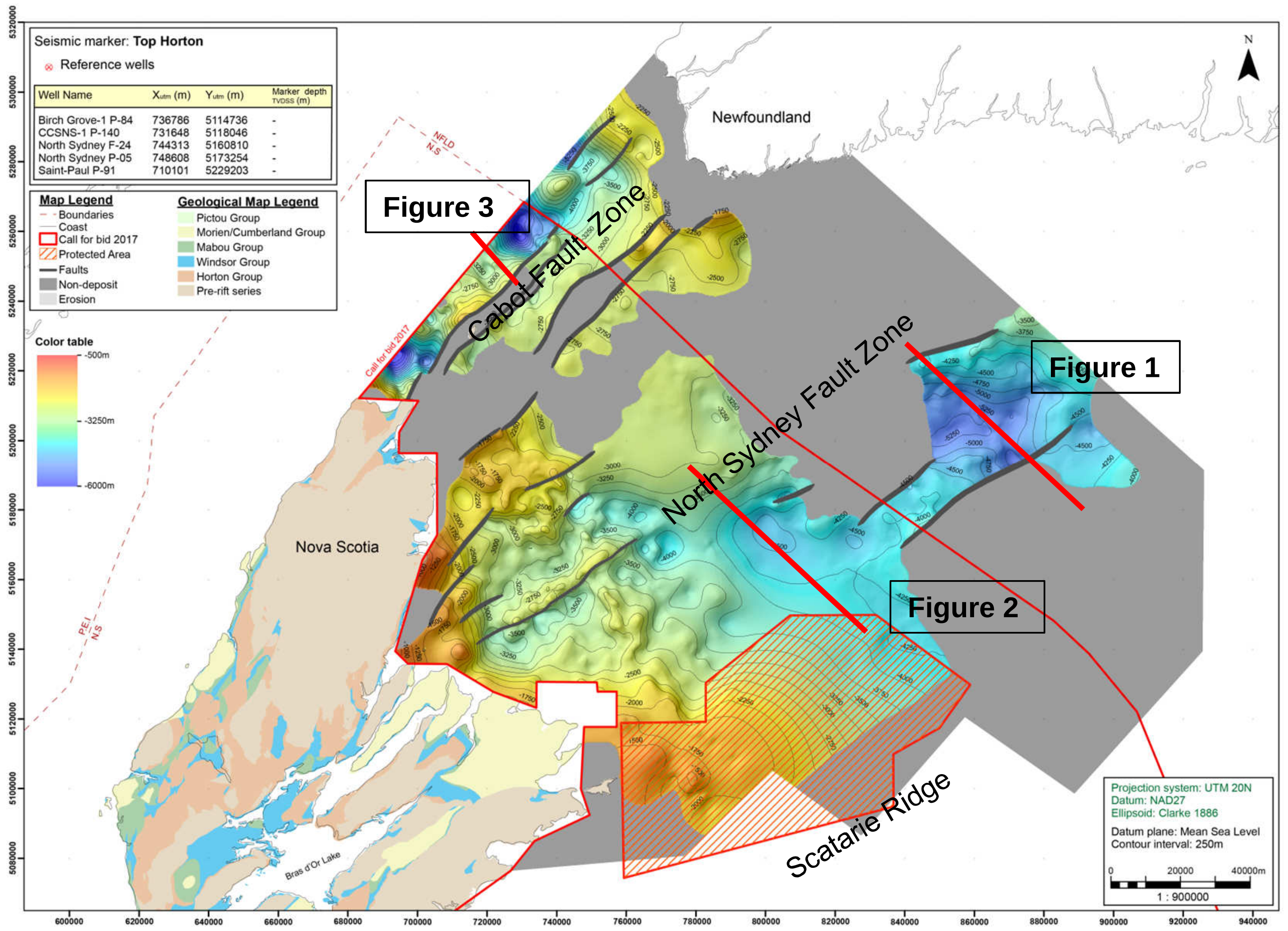


Figure 3: Depth (TVDSS) Map of the Top Horton Group

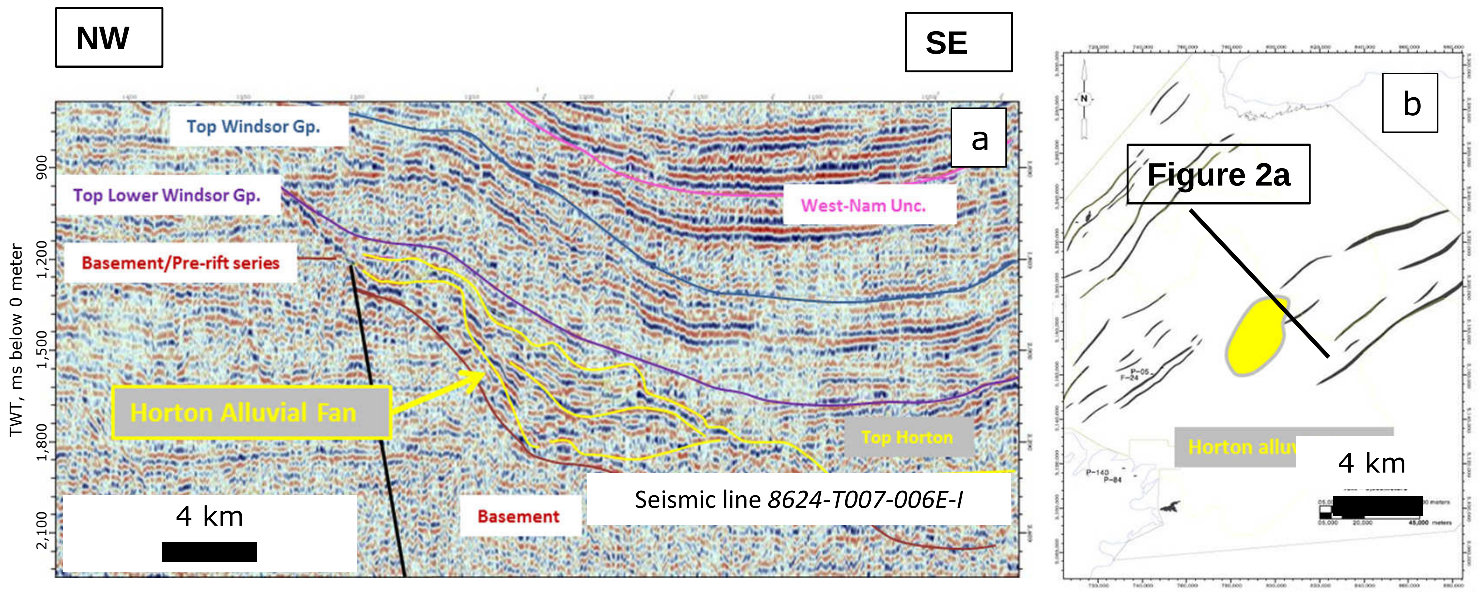


Figure 2: Horton alluvial fan a) seismic expression of a Horton alluvial fan along the graben faulted edge induced by the North Sydney Fault Zone; b) location map of the Horton alluvial fan and seismic line 8624-T007-006E-I .

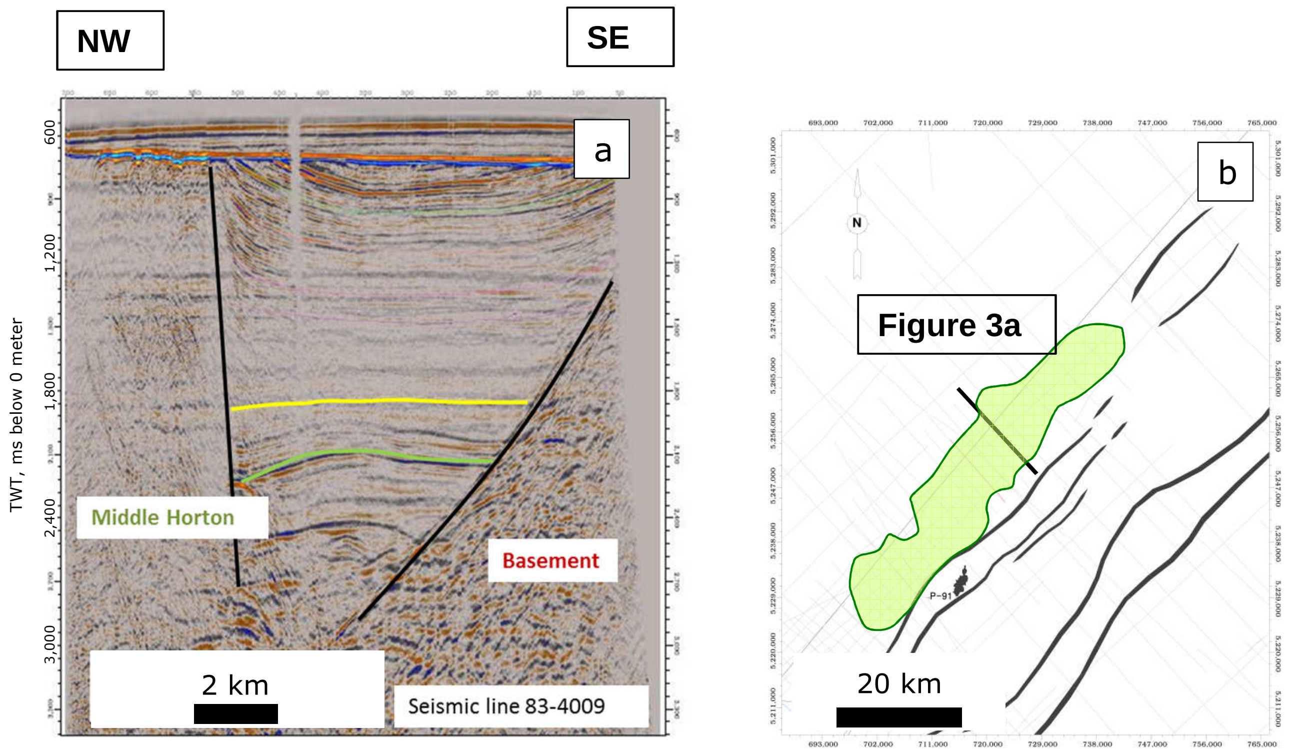


Figure 3: Middle Horton source rocks a) seismic expression of the Middle Horton strata deposited in the Searston deep pull-apart basin within the Cabot Fault Zone; b) location map of the Middle Horton extension and seismic line 83-4009.

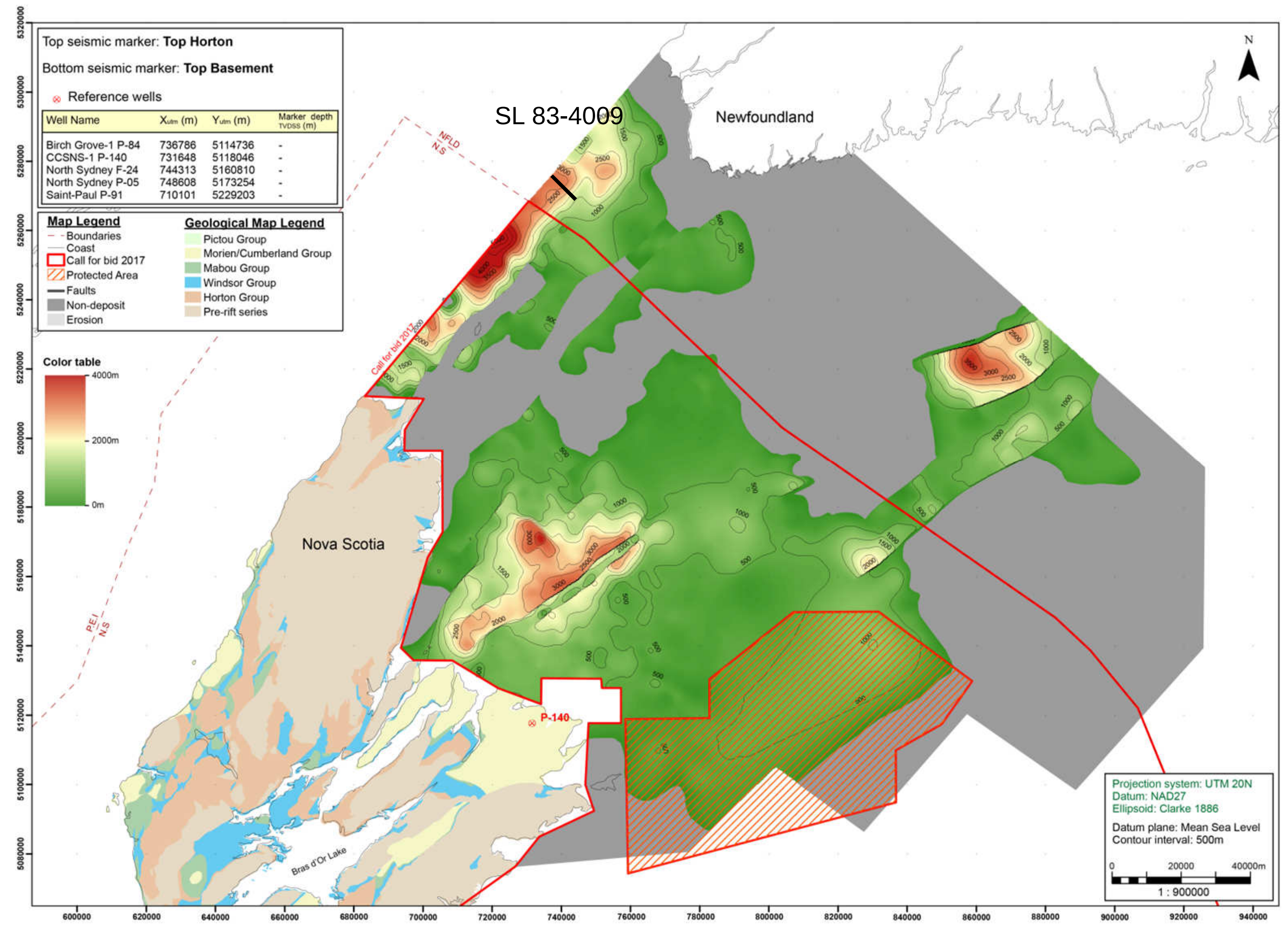


Figure 4: Thickness map of the Horton Group showing depocenters within the Searston pull-apart graben along the Cabot Fault Zone and along the North Sydney Fault Zone as well as the effect of successive unconformities.

Horizon Definition and Structural Description

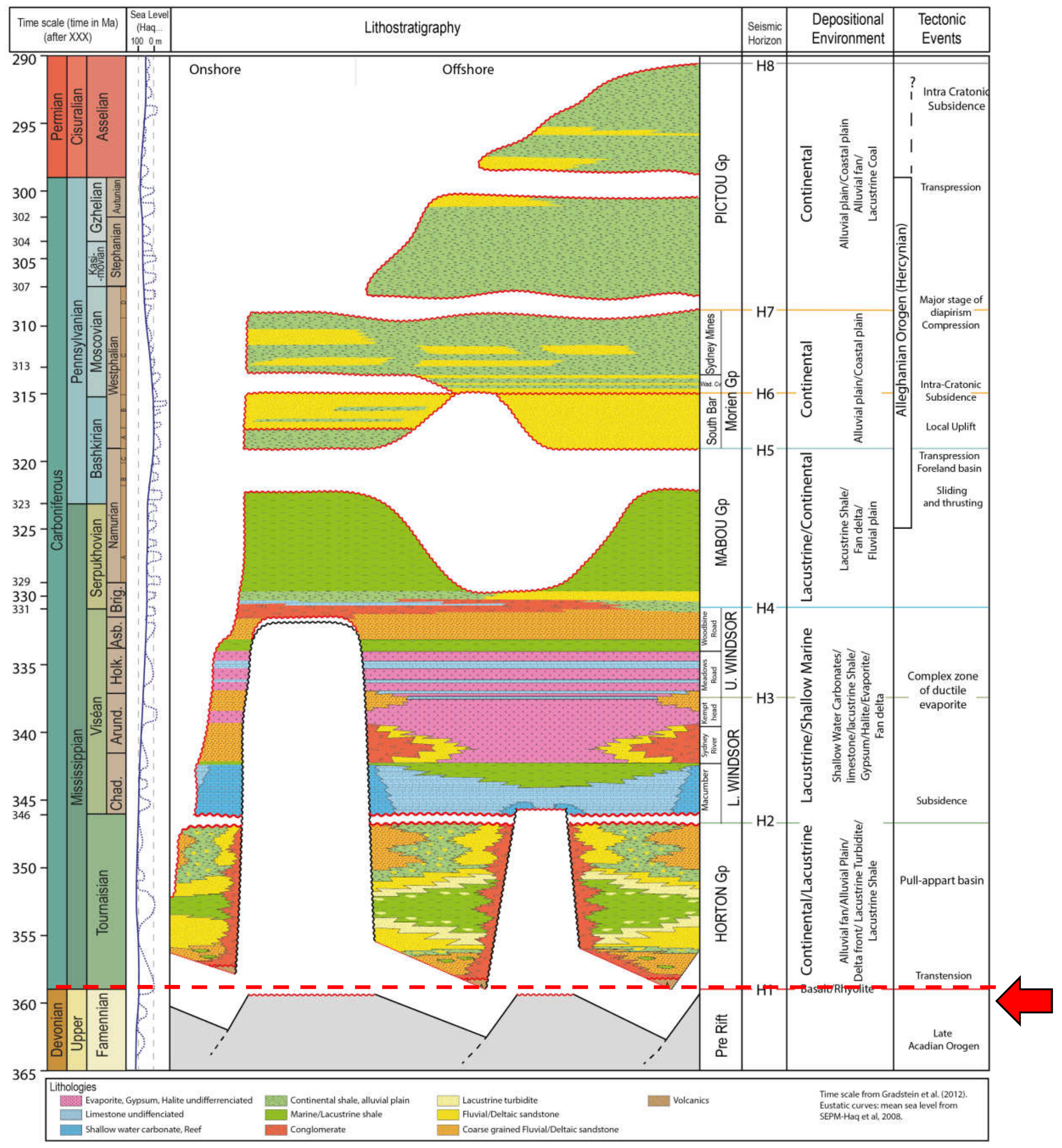
The horizon named “Top Horton Group” is an erosional surface corresponding to the top of the continental syn-rift infill that occurred during Tournaisian rifting. The age of this surface has been estimated at 346 million years (Figure 1 Pl. 3.2.1). The seismic expression of the top Horton unconformity can be enhanced through the use of instantaneous phase displays. Figure 1 shows the Top Horton truncated underneath the onlapping base marine transgression of the Windsor Group. An alluvial fan can be delineated along the eastern edge of the North Sydney Fault Zone as shown on Figure 2a. This alluvial fan is made of several lobes along the faulted edge of the graben induced by the North Sydney Fault Zone (Figure 2b). Locally a Middle Horton horizon can be picked and mapped within the deepest part of the Searston pull-apart basin as demonstrated on Figure 3a and Figure 3b. This Middle Horton horizon may correspond to the top of the intra-Horton lacustrine organic-rich shales, which are the primary source rocks within Sydney Basin.

Well to Seismic Tie and Seismic Picking Uncertainty

None of the offshore wells in Nova Scotia have penetrated the Horton Group. Seismic picking relies entirely on seismic character and reflection configurations and the knowledge of the Horton Group depositional environment within Sydney Basin.

Seismic picking is very much dependent of the picking of Basement (pre-rift series) forming the grabens infilled and onlapped by the Horton syn-rift series.

Tectono-Stratigraphical Chart



Horizon Definition and Structural Description

The horizon named “Top Basement“ is an erosional surface corresponding to the peneplanation of the Appalachian Mountains and represents the “economic basement“ of the Horton Group play. Top Basement has a composite substratum that consists of igneous rocks and deformed pre-rifts series. The age of this surface has been estimated at 355 million years. Figure 2 (instantaneous phase display) shows the presence of tilted blocks dissecting the pre-rift series preserved within the graben, and erosion of the pre-rift series over the graben shoulders. Figure 3 (reflectivity data) shows the presence of a fractured igneous batholith to the left, potentially intruded within the folded pre-rift series to the right.

Well to Seismic Tie and Seismic Picking Uncertainty

The only well that has sampled the pre-rift formations is onshore well CCSNS-1 P-140. There, strata belonging to the Mabou Group rest directly over volcanic rocks attributed to basement. Nevertheless this well to seismic correlation could not be propagated from the onshore towards the offshore. Therefore seismic picking of Top Basement, i.e. pre-rift series, relies entirely on seismic character and reflections in areas not affected by multiples. The interpretation is highly uncertain except where picking could be undertaken over portions of the 2010 seismic survey lines.

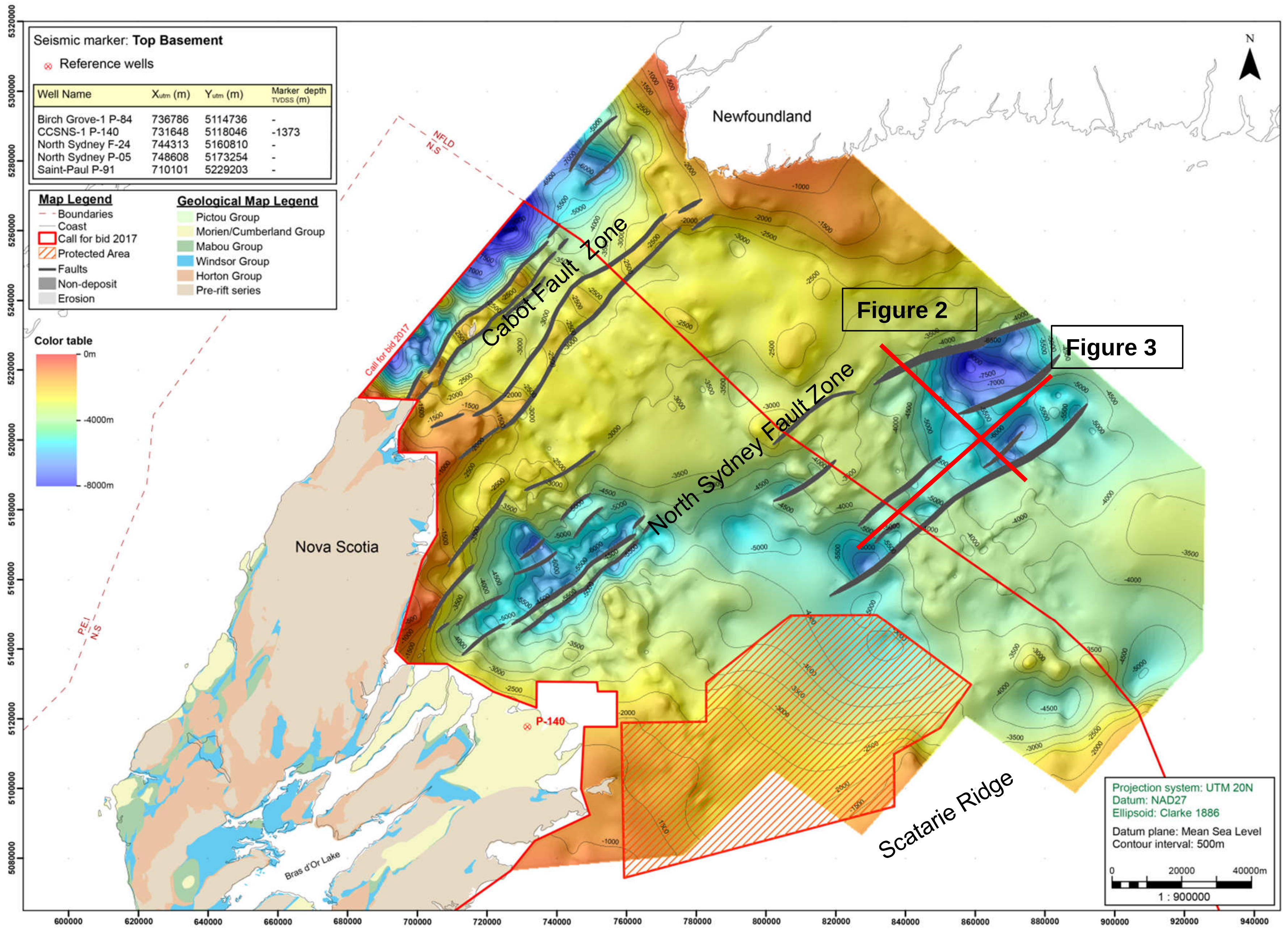


Figure 1: Depth (TVDSS) Map of the basement and pre-rift series. The fault pattern is dominated by a series of SE-NW dextral strike slip faults such as the Cabot and North Sydney Fault Zones.

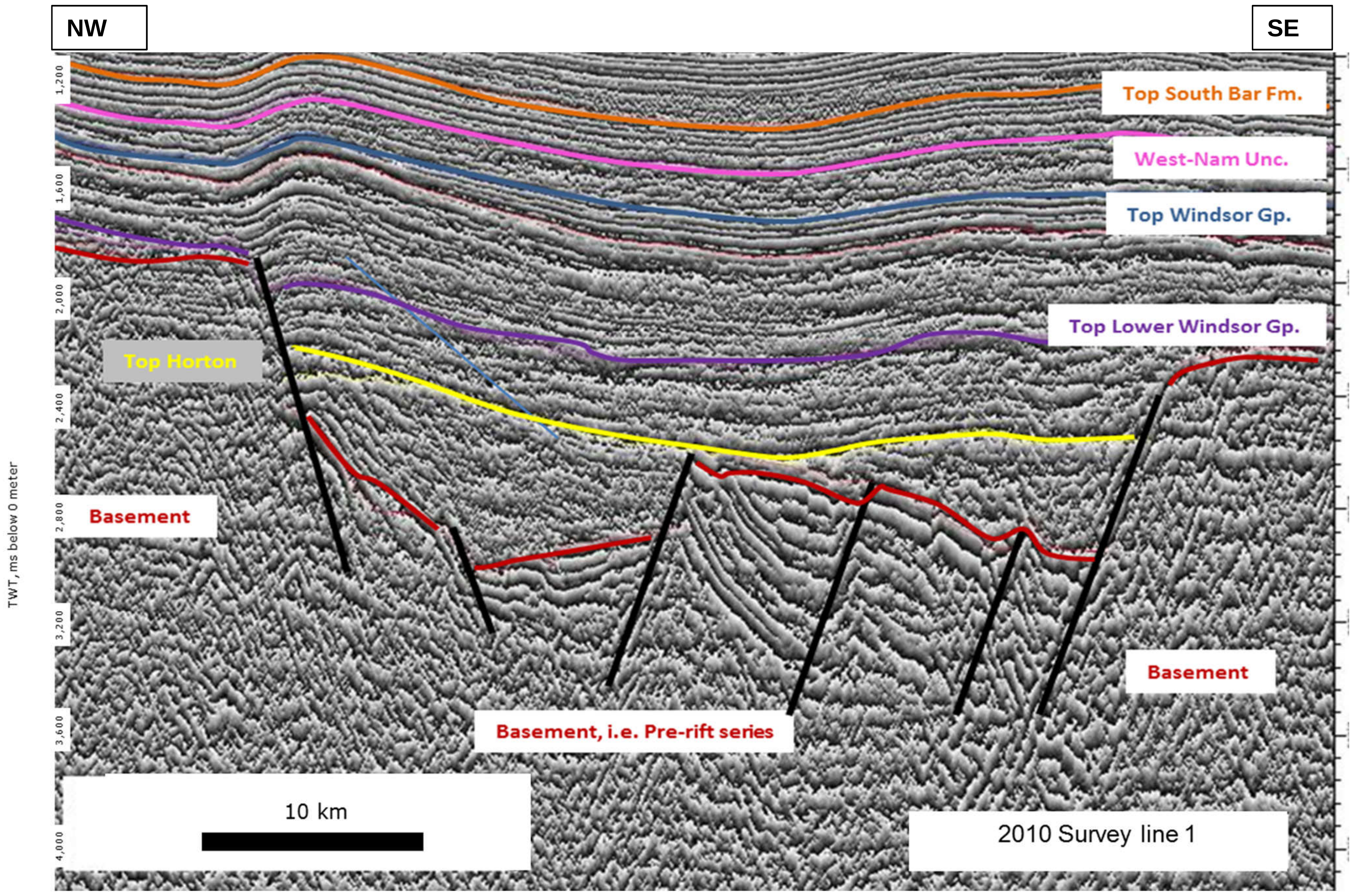


Figure 2: Seismic expression of the Basement and pre-rift series. Two types of seismic facies are observed: the chaotic and transparent SF is interpreted as intrusive or metamorphic basement while stratified SF represents the pre-rift series. See seismic line locations on Figure 1.

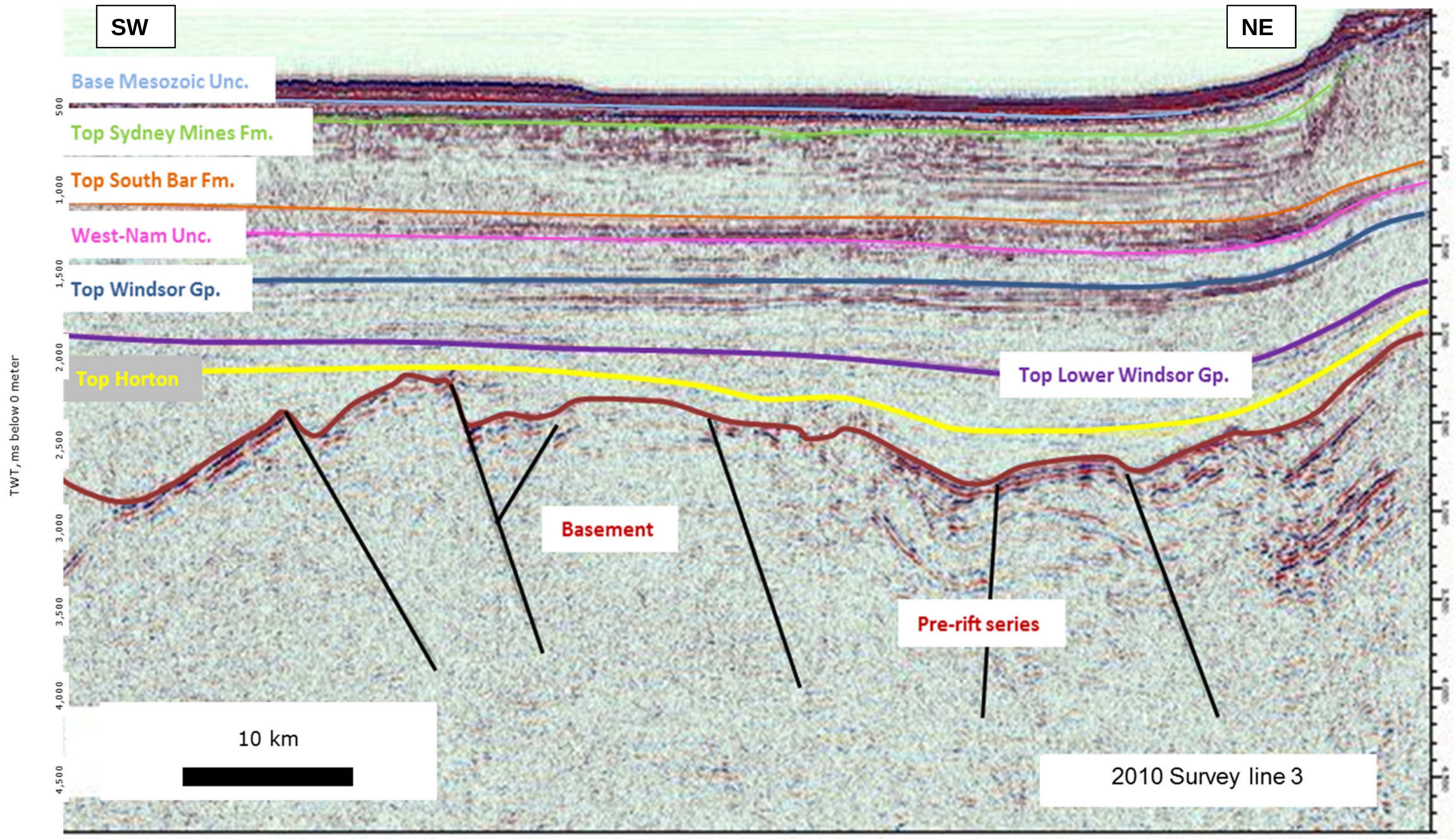


Figure 3: Seismic expression of the Basement and pre-rift series within the Sydney Basin depocenter. The left part is interpreted as cristalline basement and the right part shows folded pre-rift series. See seismic line locations on Figure 1.

Basement and Pre-Rift Series